A Text Book on

PRACTICAL PHYSICS

PARTS I & II

for

B. Sc. Students

(Three year Degree Course)

Prof

K. G. MAZUMDAR

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A TEXT-BOOK ON
PRACTICAL PHYSICS

PARTS I & II

A TEXT-BOOK ON PRACTICAL PHYSICS

FOR THREE-YEAR DEGREE COURSE (PASS)

PART I
[General Physics, Heat, Sound and Magnetism]
&
PART II
[Light and Electricity]

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By

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In Memory of
My
Late Elder Brother
N. G. Mazumdar

PREFACE TO THE FIRST EDITION

The present 'Text-Book on Practical Physics for Three-year Degree Course' is meant for the Parts I and II examinations of B.Sc. Students. Examination of Part I will be held at the end of two years while the examination of Part II will be held at the end of third year. It completely covers the present syllabus of B.Sc. examinations of the different Universities of West Bengal (such as Calcutta, North Bengal and Burdwan) as well as of the other States of India. The experiments which are not intended for the Pass Students of a University are separately mentioned so that students may not find difficulty in choosing the experiments which they will have to perform.

The manner of presentations of the subject-matter of the book has been made very simple. The procedure and recording of the results of an experiment are arranged in a very systematic manner. Oral questions and their answers are given at the end of each experiment so that the theoretical side of the experiment may be clear to the students.

In this connection. I must express my indebtedness to Dr. D. B. Sinha of Calcutta University, Prof. P. K. Chatterjee of Shibpur Engineering College, Prof. B. N. Ghose of Krishnagar College, Prof. M. L. Choudhuri of Jalpaiguri College, Profs. B. D. Sarkar and G. Ball of St. Xavier's College ; Prof. T. P. Chatterjee of Cooch-behar College for their valuable suggestions to raise the standard of the book. I am also thankful to Profs. S. Rakshit and B. Mukherjee of Vidyasagar College, Profs. N. K. Dasgupta and M. Mukherjee of Bangabasi College for their appreciations of the book. My colleagues here, *viz*. Profs. P. Sen ; S Mukherjee ; S. Das ; C. Bose ; S. Ghosh and B. Bhattacharyya gave an immense help to me for the greater benefit of students. I shall be highly thankful to my colleagues of different colleges to have their valuable suggestions to improve the standard of the book.

Asutosh College,
30th May, 1961.

K. G. Mazumdar.

PREFACE TO THE FIFTH EDITION

In this edition, many changes are made. Some of the experiments are re-written and one new experiment is added to cover the revised syllabus of different Universities. Many tables are modified and some new blocks are added to make the subjects explicit to the students.

In this connection, I must express may gratitude to Prof. Sukumar Ghosh of Jhargram Raj College, and Prof. B. F. Bhattacharyya of Nawadip Vidyasagar College, for their valuable suggestions. I am also thankful to my colleagues, Profs. A. Bhattacharyya ; A. Ganguli ; N. Mitra ; H. Mukherjee and S. Banerjee for their helpful suggestions.

Asutosh College,
4th October, 1963.
K. G. Mazumdar.

PREFACE TO THE EIGHTH EDITION

Some modifications are made in this edition. A new experiment (No. 39) has been added in Part II to serve the needs of the students of other Universities. Some tables are modified so that the recording of the results of experiments may be more convenient. It is my belief that the book in its present form will be much more helpful to the students than before.

Asutosh College,
18th February, 1967.
K. G. Mazumdar.

PREFACE TO THE NINTH EDITION

In this edition a minor change is made in experiment 54 of Part II, regarding the block and corrections of the apparatus. No other changes are made anywhere. I hope, by this modification, the students will not find difficulty in performing the experiment 54.

Asutosh College,
7th October, 1968.
K. G. Mazumdar.

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CHAPTER I

INTRODUCTORY

1. Errors in measurement and the methods of minimising them.

To determine a physical constant in the laboratory, we are to measure various quantities which are connected with that physical constant by a formula. Measurements of the quantities in the formula involve errors which might be (*a*) *Random errors*, (*b*) *Systematic errors.*

(*a*) *Random errors.*—Random errors might be due to (*i*) small changes in the condition of the experiment, (*ii*) the incorrect judgement of the observer in taking different observations.

Examples : The small change in the null point of an electrical experiment is an example of random error. This error is caused by the change in the condition of the experiment, due to the heating effect of current and other causes.

In measuring a length or an angle with the help of a scale and pointer, the observer usually makes an error in estimating the coincidence of the pointer with the scale reading or in assessing the correct position of the pointer when it lies between the two consecutive marks of the scale. This error, which is due to the incorrect judgement of the observer, is also an example of random errors.

These random errors are distributed on both sides of the correct value according to the law of probability. Hence large random errors are less probable to occur than small ones. If we take a large number of observations of the same quantity then it is very likely that the majority of these observations will carry small errors which might be positive or negative. The error will be positive or negative according as the observed reading is above or below the correct reading. Thus *random errors can be made minimum by taking the arithmetic mean of the large number of observations of the same quantity.* This arithmetic mean will be very close to the correct result. If one or two observed readings differ widely from the rest then they should be *rejected* in finding the mean.

(*b*) *Systematic errors.*—During the course of the performance of an experiment certain sources of error operate constantly or systematically making the readings systematically greater or smaller than the correct reading. These errors are called **systematic errors.** To eliminate these errors, different methods are adopted in different cases.

(*i*) In some cases, the errors are determined previously and the readings are corrected accordingly. Hence these errors become ineffective in contributing any error to the final result.

The zero error in micrometer screw and slide callipers, the index error in optical bench, the end error in metre bridge, and in fact, all instrumental errors belong to this category.

(*ii*) Again in some cases the error is allowed to occur and finally it is eliminated with the help of the data obtained during the experiment.

Thus during the determination of the specific heat of a solid or of a liquid by the method of mixture, the loss of heat by radiation is allowed to occur and finally this loss is corrected for, from the record of the temperature of the calorimeter at different times.

(*iii*) There are also cases in which the errors are eliminated by repeating the experiment under different conditions.

Thus in the determination of the velocity of sound in moist air by resonance column method, the error due to the end effect is eliminated by noting the lengths of the resonant column of air, when resonance occurs between the fork and the fundamental tone and first overtone of the air column.

2. *Limit of accuracy.*

Before an experiment is undertaken, the expected maximum error can be calculated and this maximum error so calculated, determines the expected limit of accuracy.

Suppose we are going to measure the value of a physical quantity u by the observations of the three quantities x, y and z whose true values are related to u by the equation,

$$u = x^{\alpha} y^{\beta} z^{-\gamma} \quad \ldots \quad \ldots \quad (1)$$

Let the expected small errors in the measurement of the quantities, x, y and z be respectively $\pm\delta x$, $\pm\delta y$ and $\pm\delta z$, so that the error in u, by the use of these observed quantities, is $\pm\delta u$. The proportional or relative error in u is $\frac{\delta u}{u}$ and this will be maximum when the individual errors have their maximum expected values and all conspire in the same sense, *i.e.* when the actual errors are, $+\delta x$, $+\delta y$ and $-\delta z$. By the help of logarithmic differentiation we get from the equation (1),

$$\left(\frac{\delta u}{u}\right)_{\text{max.}} = \alpha . \frac{\delta x}{x} + \beta . \frac{\delta y}{y} + \gamma . \frac{\delta z}{z} \quad \ldots \quad (2)$$

Thus the rule to find the maximum proportional error in the value of u can be derived from the relation (2) and can be stated as follows :

Multiply the proportional error of each factor (viz. x, y, z) by the numerical value of the power to which each factor is raised and then add all the terms so obtained.

The sum thus obtained will give the proportional error in the result of u. When the proportional error of a quantity is multiplied by 100 we get the percentage error of that quantity. Thus it is evident from the equation (2) that a small error in the measurement of the quantity having highest power will contribute maximum percentage error in the value of u. Hence the quantity having highest power should be measured with as great precision as possible.

Examples : (*a*) In the determination of the rigidity (n) of a wire of length l and radius r, we have the formula,

$$n = \frac{360\, lgd}{\pi^2 r^4} \cdot \left(\frac{m}{\phi}\right) \qquad \ldots \qquad \ldots \quad (3)$$

The least length which can be measured by a micrometer screw is ·01 mm. Suppose there is an error of ·01 mm. in the measurement of the radius (r) of the wire. The value obtained for radius is say ·50 mm. Hence the percentage error in the determination of r is $\frac{\cdot 01}{\cdot 50} \times 100 = 2\%$. Its contribution to the measurement of the rigidity (n) of the wire is thus 8%. Thus the radius of the wire should be measured with great precision.

(*b*) In the determination of the resistance R of a wire by employing a metre bridge, suppose we get the null point at a distance x from the left end of the metre bridge wire of total length l. If the unknown resistance R is placed in the left gap, while the known resistance P is inserted in the right gap, then by the Wheatstone bridge principle we have,

$$R = P\frac{x}{l-x} \qquad \ldots \qquad \ldots \quad (4)$$

Taking logarithmic differentiation of eqn. (4) we get,

$$\frac{\delta R}{R} = \frac{\delta x}{x} + \frac{\delta x}{l-x}$$

$$\therefore \quad \frac{\delta R}{R} = \frac{l\delta x}{x(l-x)} \qquad \ldots \qquad \ldots \quad (5)$$

Proportional error in R $\left(viz.\ \frac{\delta R}{R}\right)$ will be minimum when $x(l-x)$ is maximum, *i.e.* when the differential co-efficient of $x(l-x)$ is zero. This will happen when $x = l/2$. Thus, error in measuring R will be minimum when the balance point is obtained at the middle of the wire.

(*c*) By using a deflection magnetometer we can find $\frac{M}{H}$, from the relation,

$$\frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \tan\theta \qquad \ldots \qquad \ldots \quad (6)$$

Where, M = magnetic moment of the deflecting magnet,
H = earth's horizontal intensity,
d = distance between the centres of the deflecting magnet and the magnetic needle,
θ = deflection of the needle,
l = half the length of the deflecting magnet.

When l is small in comparison with d, equation (6) may be written as,

$$y = \frac{M}{H} = \frac{d^3 \tan\theta}{2} \qquad \ldots \qquad \ldots \quad (7)$$

$$\text{or,} \quad \frac{\delta v}{y} = 3\frac{\delta d}{d} + 2\frac{\delta\theta}{\sin 2\theta} \qquad \ldots \qquad \ldots \quad (8)$$

Thus the error δy in the measurement of y i.e. of M/H will be minimum when d is made large and θ is kept at 45°.

Again by using vibration magnetometer we can find MH from the relation,

$$MH = \frac{4\pi^2 I}{T^2} \qquad \ldots \qquad \ldots \quad (9)$$

Where, I = moment of inertia of the deflecting magnet,
T = period of oscillation of the magnet in the earth's horizontal field.

If MH be taken as equal to x then the maximum proportional error in x is given by,

$$\frac{\delta x}{x} = \frac{\delta I}{I} - 2\frac{\delta T}{T} \qquad \ldots \qquad \ldots \quad (10)$$

As the period of oscillation T is small, a small error $-\delta T$ in the measurement of T will cause a large error in x. Hence T should be measured very accurately. As I is large, a small error $+\delta I$ in the measurement of I will not contribute large error in the measurement of x, i.e. of MH.

3. *Computation of the result.*

It has been shown before that when a physical quantity u is related with the quantities x, y and z by the equation.

$u = x^{\alpha}\, y^{\beta}\, z^{-\gamma}$, the maximum proportional error in u is given by,

$$\left(\frac{\delta u}{u}\right)_{\text{max.}} = \alpha\frac{\delta x}{x} + \beta\frac{\delta y}{y} + \gamma\frac{\delta z}{z} \qquad \ldots \qquad \ldots \quad (1)$$

From the eqn. (1) the proportional error in x, y and z can be calculated and hence that in u can also be found out. Thus we see that there is a limit to the accuracy of the value of u obtained from the observed values of x, y and z. Hence it is entirely unnecessary to calculate to, and to retain, a large number of significant digits in the value of u than what the observations merit. So the number of significant digits in the value of u should be cut down to such an extent as can be claimed to be reliable.

Example : In order to determine the pressure co-efficient (α) of a gas, the pressure is measured by measuring the difference of mercury levels in the two arms by means of a scale which can read up to ·1 cm. The temperature is measured by a thermometer which can read up to ·5°C (say).

Let us accept the following data :

Pressure of air at $87^\circ C = P_t = 94{\cdot}5$ cms.

„ „ „ „ $0^\circ C = P_0 = 72{\cdot}31$ cms. (by extrapolation from the curve)

Rise of temperature $= t^\circ C = 87^\circ C$.

$$\alpha = \frac{\text{increase of pressure}}{\text{pressure at } 0^\circ C \times \text{rise of temperature}}$$

$$= \frac{22{\cdot}19}{72{\cdot}31 \times 87} = {\cdot}003527 \text{ per } ^\circ C$$

Maximum expected error in noting the readings of the two arms = ·2 cm.

„ „ „ „ „ P_0 from the curve = ·5 cm. (say)

„ „ „ „ „ the change of temperature = 1°C (say)

$$\text{Proportional error in the change of pressure} = \frac{{\cdot}2}{22{\cdot}19} = {\cdot}009014$$

$$\text{„ „ „ measurement of } P_0 = \frac{{\cdot}5}{72{\cdot}31} = {\cdot}006915$$

$$\text{„ „ „ measurement of } t = \frac{1}{87} = {\cdot}01149$$

As each of the quantities has the first power in the formula,
the proportional error in $\propto = \dot{}009014 + \dot{}006915 + \dot{}01149 = \dot{}027419$.

Percentage error in the value of $\propto = 2{\cdot}7\%$.

Error in the value of $\propto = \dot{}02742 \times \dot{}003527 = \dot{}000097$ (nearly).

Thus the result, ·003527 is reliable up to four places of decimals. Hence the result should be recorded up to two significant figures as ·0035.

4. *Probable error.*

Probable error denotes the limits, on either side of the most probable value of a quantity, so that there is the even chance of the true result lying between these limits. The most probable value of a quantity can be calculated statistically from a very *large number of observations carrying random errors only.*

For all practical purposes, the probable error is sometimes intended to stand for mean deviation or for standard deviation. But strictly speaking, it has a meaning different from either.

If $x_1, x_2 \cdots\cdots x_n$ be the values of n different observations of the same quantity u, then their arithmetic mean m may be taken as the nearest approach to the correct value of u. We are now to find the limits within which the errors of u may lie. Deviations of individual observations are given by, $d_1 = (x_1 - m)$, $d_2 = (x_2 - m) \ldots\ldots d_n = (x_n - m)$. If d be the arithmetic mean of the numerical values of these deviations then d will represent the *mean error* and for all practical purposes, we may write,

$$u = m \pm d.$$

Sometimes instead of taking the arithmetic mean of the numerical values of these deviations, the root mean square of these deviations are found out which is called *standard deviation* (D). Thus the value of the standard deviation is given by,

$$D = \sqrt{\frac{d_1^2 + d_2^2 + \cdots + d_n^2}{n}} = \sqrt{\frac{\Sigma d^2}{n}}.$$

$$\therefore \quad u = m \pm D.$$

The *probable error* can be shown to be approximately equal to

$$\theta = \frac{2D}{3\sqrt{n}}.$$

Hence the result may be written as,

$$u = m \pm \theta.$$

Example : Suppose in the measurement of the E.M.F. (E) of a cell by potentiometer we get different values of the E.M.F. From these different values, deviations, mean deviation, standard deviation, and probable error are calculated which are shown in the table below :

Different values of E.M.F.	Mean E.M.F. 'm'	Deviation	Mean deviation 'd'	Standard deviation $D=\sqrt{\frac{\Sigma}{n}}$	Probable error $\theta=\frac{2D}{3\sqrt{n}}$
2		–·05			
2·1		+·05			
1·98	2·05	–·07	·08	·088	·026
2·2		+·15			
1·97		–·08			

5. *Drawing of graphs.*

The following procedure should be adopted in drawing a graph :

(i) Representation of the variables along the axes :—

When the two variables, connected with each other by a formula, are to be plotted on a graph paper, the independent variable should be plotted along the x-axis while the dependent variable should be plotted along the y-axis. That variable which always changes with the change of another variable, is called dependent variable while the latter variable is called independent variable. The variable plotted along an axis should be written by the side of that axis.

Examples : (a) In $(u-v)$ graph, the image distance v always changes with the change of the object distance u. Hence u is the independent variable while v is the dependent variable.

(b) In $(P-T)$ graph, the pressure P of a gas always changes as the temperature T changes when the volume is kept constant. Thus, temperature is the independent variable while pressure is the dependent variable.

(ii) Marking of origin : Minimum values of the data of the two variables should be first selected. Then the round numbers smaller than those minimum values should be taken as origins for the two variables. The values of the origins of the two variables *may not necessarily be equal.*

Example : The data connecting the object distance u and image distance v of a convex lens are as follows :

u in cm	28·4	21·6	19·5	16
v in cm.	12·5	16	17·5	21·6

Here the minimum values of u and v are 16 cms. and 12·5 cms. respectively. Hence the values of the origins for u and v should be 15 and 10 cms. respectively.

(iii) Selection of units along axes :—First the round numbers greater than the maximum data of the two variables should be determined. Then the difference between this maximum round number and the value of the origin selected along an axis, should be divided by the number of smallest divisions available along that particular axis of the graph paper. The quotient will give the value of a smallest division along this axis. The number of smallest divisions along the axis should be so chosen (not necessarily the total number of divisions available) that the quotient becomes a simple number as far as possible.

(iv) Marking of data along the axes :—After marking origins, figures are to be put after each large divisions of the graph paper (*i.e.* after 10 small divisions) from which the value of a small division can be found out (mentioning the value of a small division is unnecessary).

(v) Plotting :—Each pair of the variable is then to be plotted and the point should be marked by a small cross or by a small dot surrounded by a light circle (co-ordinates of the point need not be written by the side of the point unless it is required for quick inspection).

(vi) Joining of points to have the curve :—The marked points should then be joined by a fine medium pencil to have a continuous curve (not broken curve). In drawing such a continuous curve, one or two points far away from the curve, may be rejected. Large deviations of these points from the curve indicate that these points are incorrectly recorded. The curve should be drawn in such a way that it passes through the majority of points and the other points are evenly distributed on both sides of the curve. In the case of a straight line graph, the line should be drawn with the help of a scale so that it passes through the majority of points and other points are evenly distributed on both sides of the straight line.

(vii) Finding the value from the graph :—If a particular value of the abscissa (or ordinate) be given, then the corresponding value of the ordinate (or abscissa) can be determined from the graph. From the given point of the abscissa (or ordinate), whose value is given, an ordinate (or abscissa) is to be drawn to cut the curve at a point. From this point of the curve a horizontal line (or vertical line) is to be drawn to cut the y-axis (or x-axis) at a point. The value of the y-axis (or x-axis) corresponding to this cutting point, gives the value of the ordinate (or abscissa), the value of whose abscissa (or ordinate) is given.

Illustrative graph :—To illustrate the above points in drawing a graph, the following data connecting the frequency and corresponding length of a given string, stretched by a constant load, are taken. The graph is shown in Fig. 1.

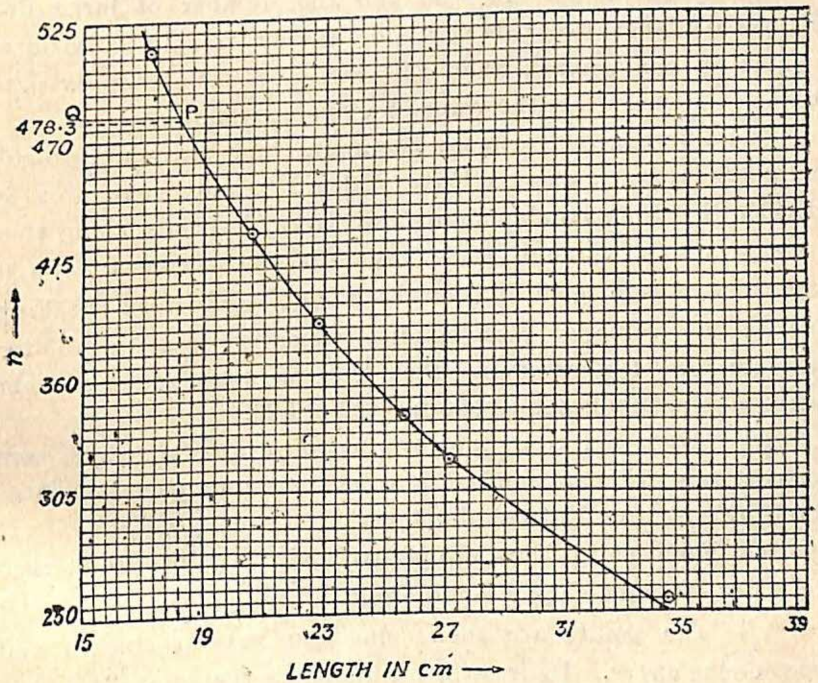

Fig. 1

Frequency (n).	256	320	341·3	384	426·6	X	512
Length in cm. (l)	34·4	27·1	25·6	22·8	20·5	18·2	17·2

(*i*) Here the variation of the length l of a string will cause a variation of its frequency n. Hence l is the independent variable which is plotted along x-axis while n is the dependent variable which is plotted along y-axis.

(*ii*) The minimum data regarding l and n are respectively 17·2 cms. and 256. The corresponding round numbers smaller than those are 15 cms. and 250 which are taken as origins for l and n respectively.

(*iii*) The maximum data regarding l and n are respectively 34·4 cms. and 512. The corresponding round numbers greater than those are respectively 35 cms. (for l) and 520 (for n). The difference between the maximum and minimum round numbers along the x-axis is $(35-15)=20$ and the number of large divisions available along this axis is 6. If we take only 5 divisions (which is convenient), then the value of each large division becomes 4 cms. while the value of a small division is ·4 cm.

The difference between the maximum and minimum round numbers along y-axis is $(520-250)=270$ and when this is divided by the available number of large divisions along this axis, *viz.*, 5, the value of each large division becomes 54 and the value of each small division becomes 5·4. Instead of taking 5·4 as the value of each small division, we take it as 5·5 for convenience of plotting, so that the maximum round number along y-axis now becomes 525 instead of 520.

(*iv*) After marking the origins of l and n which are respectively 15 cms. and 250, values are put after each large division (*i.e.* after 10 small divisions).

(*v*) Each pair of data are plotted and the points are marked by a dot surrounded by a small circle.

(*vi*) The points are then joined to have a smooth and continuous curve. In drawing such a curve the point (34·4,256), which is slightly away from the curve is ignored for it is evident that this point was not correctly recorded.

(*vii*) The unknown frequency X, corresponding to length 18·2 cms. is found out from the graph by drawing a vertical line from 18·2 until it cuts the curve at P. From P a horizontal line is drawn to cut the y-axis at Q. The value of y-axis corresponding to Q is 478·3 which is the frequency corresponding to length 18·2 cms. The actual value is however 480.

6. *Recording of experiments in a note book.*

The following procedure should be adopted in writing an experiment in the note book :—

(*i*) The heading of the experiment should be written in block capitals and its language should clearly indicate the quantity to be measured.

(*ii*) A short description of the apparatus should be given. Then theory and procedure of experiment should be written down. A neat sketch of the apparatus employed or connections of the apparatus should be given on the left-hand page with a fine medium pencil.

(*iii*) All data should be recorded in the order in which they are taken and in *tabular form wherever possible.*

(*iv*) By putting the data in proper *units* in the formula, the result should be calculated. Calculations will have to be shown on the left-hand page and log-table should be employed for this purpose. Proper unit must be given by the side of the result calculated.

(*v*) Lastly, the precaution necessary to arrive at the correct result should be stated.

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CHAPTER II

GENERAL PHYSICS

7. *Uses of, (a) Diagonal Scale and (b) Vernier Scale.*

(a) Diagonal Scale.

Diagonal Scale is a device in which the measurement of length can be extended up to 1/100th of an inch or centimetre without any further subdivision of the smallest division of the main scale.

Construction : To construct such a scale, an extra division of the scale, either an inch or a centimetre, is to be taken at the left end of the zero line of the scale. In the Fig. 2, a scale graduated in inches is shown and the extra division ($PQRS$) taken is an inch. The top side QP as well as the bottom side RS of this extra division, are divided into 10 equal parts by points, which are marked from 0 (at the points Q and R of the lines QP and RS respectively of this extra division) to 10 (at the points P and S of the lines QP and RS respectively of this extra division) by steps of 2 divisions. The vertical side SP of this extra division is also divided into 10 equal parts by points which are numbered from 0 (at the bottom point S) to 10 (at the top point P) by steps of 2 divisions. From these

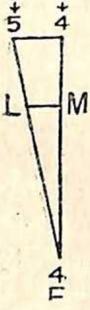

Fig. 2(a)

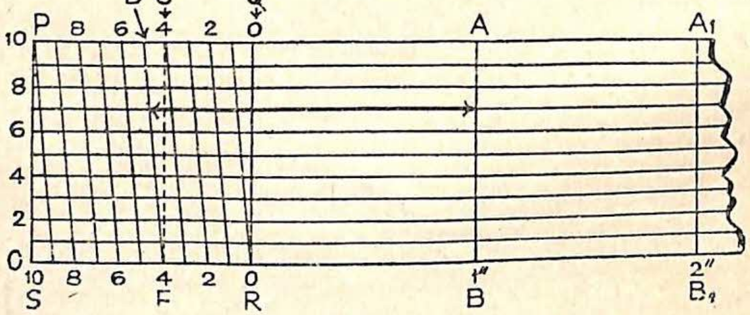

Fig. 2

points of the vertical side SP of the extra division, horizontal lines are drawn which are parallel to the length $SRBB_1$ of the scale. Now diagonal lines are drawn by joining the points, 0,1,2,..... 9 on the bottom side RS to the points, 1, 2, 3,......10 on the top side QP respectively of the extra division. Thus the construction of the diagonal scale, at the extra division taken at the left side of the 0-line of the scale, is now complete.

Use : Suppose the length to be measured lies betweeen 1 and 2 inches. A divider is taken and its two arms are gradually opened until the pointed ends of these two arms just touch the two extreme ends of given length. Now one pointed end of the divider is put in contact with the point B of the AB line (1 inch line) and it is moved towards the side PQ of the extra division so that the end of the divider in contact with B, always moves over the line BA. This movement of the divider towards PQ should be continued until the other end of the divider just comes in touch with the point of intersection of a horizontal line and a diagonal line. In Fig. 2, the other end of the divider comes in touch with the point of intersection of the 7th horizontal line and the diagonal line formed by joining the points 4 (on RS) and 5 (on PQ). The required length would be 1·47 inches.

Proof : Suppose FC is the vertical line joining the points 4 and 4 on SR and PQ respectively while FD is the diagonal line formed by joining the points 4 (on RS) and 5 (on PQ) as is separately shown in Fig. 2(a). ML is the extra length beyond the $(4-4)$ line (which represents 1·4 inches) which is to be added to 1·4 inches to get the correct length. From similar triangles, FCD and FML,

$$\frac{ML}{CD}=\frac{FM}{FC}=\frac{\cdot 7\,FC}{FC}=\cdot 7$$

$\therefore\quad ML=\cdot 7\times CD=\cdot 7\times\cdot 1=\cdot 07$ inches $[\because\quad CD=\cdot 1$ inch $]$.

The required length (as given in the Fig. 2) = 1·47 inches.

(b) Vernier Scale.

This is a device (invented by P. Vernier in 1631) by which a very small length, even smaller than the smallest division of the main scale, can be measured very accurately.

Construction : For this purpose a small auxiliary scale (VV), known as the vernier scale, is taken which can slide alongside the main scale (SS) [Figs. 3 and 4]. Usually, a division of the vernier scale is slightly smaller than the smallest division of the main scale but in some cases a division of the vernier scale is slightly greater than the smallest division of the main scale (which is now practically obsolete). The length of the gap between a vernier division and the smallest division of the main scale is called **vernier constant** or least count of the vernier.

Principle : Let us take the case in which a vernier division is slightly smaller than the smallest division of the main scale. Suppose n divisions of the vernier scale become equal to $(n-1)$ smallest divisions of the main scale. Hence one vernier division will be equal to $(n-1)/n$ smallest divisions of the main scale. Thus from the meaning of the vernier constant we may write, *vernier constant* ($v.c.$) = 1 scale division (s.d.) − 1 vernier division (v.d.).

$$\text{or,} \quad v.c. = 1 \text{ s.d.} - \frac{n-1}{n} \text{ s.d.} = \frac{1}{n} \text{ s.d.} \qquad \cdots \qquad \cdots \quad (1)$$

Thus by making n large, we can measure a small fraction ($=1/n$) of the length representing one smallest division of the scale. As for example, if one scale division is 1/2 mm. and n is 50, then we can measure up to 1/100th mm. accurately.

Types of vernier : There are two distinct types of verniers which are in common use. The straight vernier (Fig. 3) is employed for the measurement of length only while circular vernier (Fig. 4) is employed to measure angles in minutes and seconds.

Straight vernier.—Straight verniers which we usually meet in different instruments in the laboratory, bear different number of divisions in the vernier scale attached to different instruments. But in all cases n vernier divisions (the value of

n is usually 10, or 20, or 50) coincide with $(n-1)$ divisions of the scale (i.e. 9 or 19 or 49 divisions of the scale). Each smallest division of the scale may be either 1 mm. or $\frac{1}{2}$ mm. We shall now discuss the values of vernier constants (*v.c.*) for those types of verniers which we usually come across in the laboratory.

(*i*) In slide callipers, and in the vernier apparatus for finding Young's modulus, the number (n) of vernier divisions is 10 while each smallest scale division (s.d.) is 1 mm. [Fig. 3].

Hence from the relation (1) we see that $v.c. = \frac{1}{n}\text{s.d.} = \frac{1}{10} \times 1$ mm.

$= {}^{\cdot}1 \text{ mm.} = {}^{\cdot}01 \text{ cm.}$

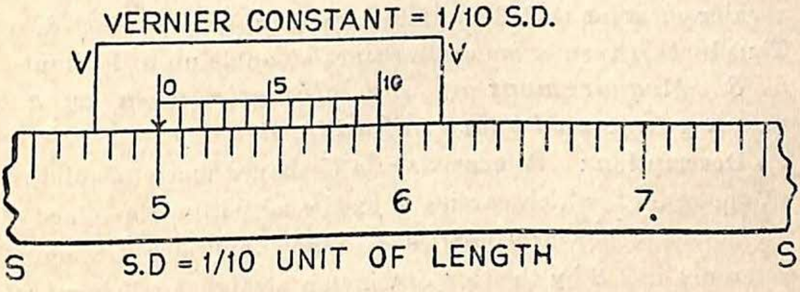

Fig. 3

(*ii*) In the verniers of barometer, and some travelling microscopes, the number (n) of vernier division is 20 while the value of each smallest scale division (s.d.) is 1 mm. Hence from the relation (1) we see that,

$$v.c. = \frac{1}{n}\text{s.d.} = \frac{1}{20} \times 1 \text{ mm.} = \frac{1}{200} \text{ cm.} = 005 \text{ cm.}$$

(*iii*) Again in some other accurate travelling microscopes, the number (n) of the vernier divisions is 50 while each smallest scale division (s.d.) is 1/2 mm. Hence, we may write,

$$v.c. = \frac{1}{n}\text{s.d.} = \frac{1}{50} \times \frac{1}{2}\text{mm.} = \frac{1}{1000} \text{ cm.} = {}^{\cdot}001 \text{ cm.}$$

Thus by this vernier, we can measure a length accurately up to 1/100 mm.

Circular vernier.—One type of circular vernier (as is employed in spectrometer) is shown in Fig. 4. Here 30 divisions of the vernier become equal to 29 divisions of the main scale the value of each of which is 1/2 degree. Here $n = 30$ and the value of a scale division is 1/2 degree. Hence the vernier constant is $(1/30) \times (1/2)$ degree *i.e.* 1/60th of a degree. Thus by this vernier we can measure an angle up to 1 minute.

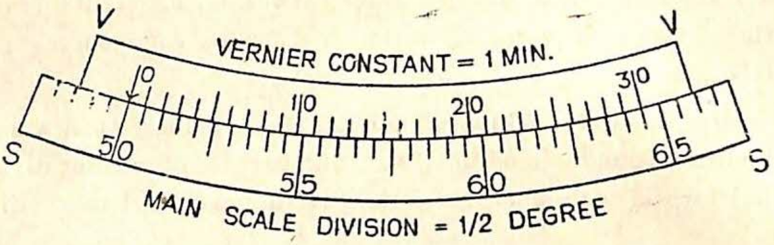

Fig. 4

8. *Measurement of the diameter of a wire by screw gauge and hence to find its density.*

Description : It consists of a U-shaped piece of solid steel P, one arm of which carries a fixed stud with a plane face at A while the other arm carries a hollow cylinder C having a reference line S by the side of which a straight scale, graduated in mm. is marked. An accurate screw provided with a cylindrical cap L moves inside the cylinder C (Fig. 5).

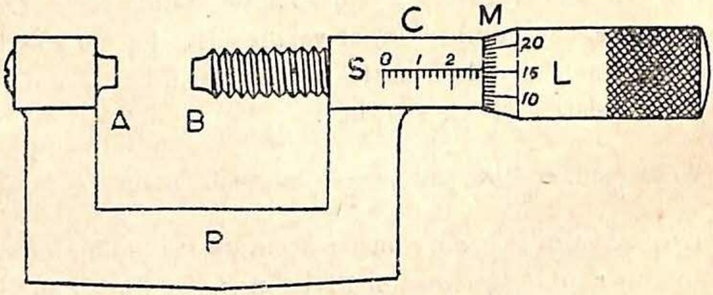

Fig. 5

The bevelled edge M of the cylindrical cap L is usually divided into 50 (or, 100) equal parts. The linear distance by which the screw moves during its one complete revolution, is called the **pitch of the screw.** The pitch of the screw is usually $\frac{1}{2}$ mm. (or, 1 mm.). The smallest distance which can be measured by this screw is $1/(2 \times 50) = \cdot 01$ mm. (or, $1/100 = \cdot 01$ mm.) and this is called the **least count** of the instrument.

The front head B of the screw is also perfectly plane. Usually, when the faces of the fixed and movable studs touch each other, the zeros of the linear and circular scales coincide. If they do not, then instrumental error comes in, which may be positive or negative according as the reading of the circular scale with respect to the reference line, is on the positive or negative side of its zero line. The number of circular scale divisions by which the instrumental error occurs, should be multiplied by the least count and this value should be subtracted from, or added to, the final mean value according as the initial circular scale reading (when there is no gap between the studs A and B) is on the positive or negative side of its zero line.

Theory : (*i*) *For screw gauge* :—A screw has both linear and rotatory movement. If the screw moves linearly by p mm. during its one complete rotation then p mm. is called the *pitch of the screw*. If there are N divisions in the circular head of the screw, then the smallest distance by which the screw will move linearly for one division rotation of the circular head is p/N mm. which is called *least count* (*l.c.*) of the instrument. If the readings of the linear and circular scales are respectively m and n then the length of the gap between the fixed stud (A) and movable stud (B) would be, $d = m + n \times (p/N) = m + n \times (l.c.)$. (1)

(*ii*) *For density measurement* :—If d mm. be the diameter of the wire (as measured by screw gauge), l cm. be its length (as measured by a scale) and m gms. be the mass (as measured by a balance), then the mass of the wire is given by, mass = cross-section × length × density.

$$\text{or,} \quad m = \frac{\pi}{4}\left(\frac{d}{10}\right)^2 \times l \times \rho.$$

Hence the density (ρ) of the material of the wire is given by,

$$\rho = \frac{m}{\frac{\pi}{4}\left(\frac{d}{10}\right)^2 \times l} \text{ gms./c.c.} \qquad \ldots \qquad \ldots \quad (2)$$

Procedure : (*i*) First, the pitch of the screw and least count of the instrument are determined. Then the movable stud is made to touch the fixed stud and the reading of the circular scale is taken with respect to reference line, to find the instrumental error (*e*), if any. The instrumental error (*e*) would be marked positive or negative according as the reading of circular scale with respect to the horizontal reference line of the linear scale, is on the positive side or negative side of its zero-mark.

(*ii*) The diameter of the wire is measured at various places to avoid the error arising out of the non-uniformity of the wire.

(*iii*) At each place, the diameter is measured in two directions at right angles to each other to avoid the error which may arise due to the wire not being circular in cross-section.

(*iv*) The mean of these diameters is corrected for instrumental error.

Experimental data :

(A) *Determination of cross-section of the wire :—*

Smallest division of the linear scale $= s = \cdots$mm.
Pitch of the screw ... ... $= p = \cdots$ mm.
No. of divisions of the circular scale $= N = \cdots$
Least count (*l.c.*) ... $= \frac{p}{N} = \cdots$mm.
Instrumental error $(e) = \ldots$divisions (negative or positive)
$= \ldots$mm. (negative or positive)

N.B. [*The instrumental error* (*e*) *with its sign is to be subtracted from the final result.*]

No. of obs.	Diameter in one direction			Diameter in Perp. direction			Mean diam. in mm. $d' = \frac{d_1+d_2}{2}$	Grand mean diam. in mm. (d')	Corrected mean in mm. is $d = (d' - e)$	Cross-section $= \frac{\pi}{4}\left(\frac{d}{10}\right)^2$ sq. cm.
	L.S.R. in mm. (S)	*C.S.R.* in mm. (*C*) = (*c.s r.* × *l.c.*)	Diameter in mm. $d_1 = (S+C)$	*L.S.R.* in mm. (S)	*C.S.R.* in mm. (C) = (*c.s.r.* × *l.c.*)	Diameter in mm. $d_2 = (S+C)$				
1.	...	...	...	...	...	...	...			
2.	...	...	...	...	...	...	...			
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	...	....	...
6.	...	...	...	...	...	...	...			

(B) *Determination of the length (l) of the wire :—*

$$l = \frac{\cdots\cdots + \cdots\cdots + \cdots\cdots}{3} = \cdots\cdots \text{cm.}$$

(C) *Determination of the mass (m) of the wire :*

$$m = \cdots gm + \cdots gm + \cdots mg + \cdots mg \cdots\cdots = \cdots\cdots gm.$$

Calculation :

$$\text{Density} = \rho = \frac{\text{mass}}{\text{volume}} = \frac{\text{mass}}{\text{cross-section} \times \text{length}}$$

$$\text{or,} \quad \rho = \frac{m}{\frac{\pi}{4}\left(\frac{d}{10}\right)^2 \times l} = \cdots\cdots \text{gms./c c.}$$

Precaution : Usually a screw misfits into the nut in which it moves. This misfit increases with the use of the instrument. Due to this misfit, the axial motion of the screw does not occur for a certain angle of rotation of its head when the direction of the rotation of the head is reversed. This lag between the linear and circular motion of the screw is called **back-lash error.** To avoid this error, the *screw should always be turned in the same direction* when taking the readings.

9. Use of a spherometer (a) to find the radius of curvature of a spherical surface, (b) to measure the thickness of a plate.

(a) To find the radius of curvature of a spherical surface.

Description : The usual form of spherometer is shown in Fig. 6. It consists of a three-legged metal frame having a nut N at the centre. The ends of the legs are on the vertices of an equilateral triangle. A fine screw S passes through the nut N at the centre and its threads are accurately cut so that the **pitch** of the screw, *i.e.*, the linear shift of the screw for one complete rotation of its head, is either ½ mm. or 1 mm. A circular disc D is fixed

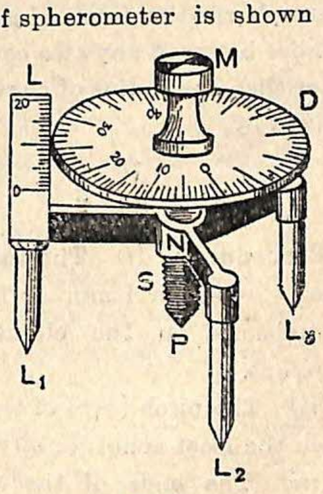

Fig. 6

to the head of the screw and the rim of this disc is usually divided into 100 equal parts. Thus the smallest distance which can be measured by this instrument, *viz.*, the **least count** of the instrument is $1/(2\times100)=1/200$ mm. or $1/100$ mm. A linear vertical scale L graduated in mm. is kept fixed by the side of the circular scale on the disc. The disc can be rotated by turning the milled head M.

Theory : (*i*) *For spherometer* :—If the central screw of spherometer moves linearly by p mm. during one complete rotation of the circular disc (having N equal divisions on the rim of the disc) attached to the head of the screw then the smallest linear distance which can be measured by spherometer is p/N mm. which is called the *least count* (*l.c.*) of the instrument while p mm. is called the *pitch* of the screw. Let the screw touch consecutively the test surface (which may be plane or spherical) and base plate (which is always plane). If for this purpose, the circular disc at the head of the screw is given m complete rotations and also an extra n divisions of the circular scale then the displacement of the screw is given by,

$$h=(mN+n)\times(l.c)\ mm. \qquad \cdots \qquad \cdots \quad (1)$$

(*ii*) *For radius of curvature measurement* :—If h be the displacement of the screw when it touches consecutively the given spherical surface and a plane surface and d be the mean distance between any two consecutive outer legs of the spherometer then the radius of curvature of the given spherical surface is given by,

$$r=\frac{d^2}{6h}+\frac{h}{2} \qquad \cdots \qquad \cdots \qquad \cdots \quad (2)$$

Procedure : (*i*) The value of each division of the linear scale ($=s=$ either 1 mm. or 1/2 mm.) as well as the number of divisions on the circular scale ($=N=$ usually 100) are found out.

(*ii*) The pitch ($=p$) of the screw is next found out from which the least count, $(l.\ c.)=p/N$ is calculated.

(*iii*) The ends of three outer legs L_1, L_2, and L_3 (Fig. 6) are put on the spherical surface whose radius of curvature is wanted. The disc D of the screw head is then rotated slowly in *one direction* only, until the end P of the screw just touches the spherical surface and this can be tested by observing the coincidence of the tip P of the screw with its image below the surface. The reading R_1 of the circular scale is then noted.

(*iv*) The spherometer is then withdrawn and placed on a glass plate. The screw-tip of the spherometer is now to be lowered or raised to touch the glass plate. The screw-tip will be lowered or raised according as the surface employed is convex or concave.

(*v*) The circular disc of the spherometer is now rotated *slowly in one direction* and at the same time the counting of its (circular disc) complete number (m) of rotations is continued until the tip of the screw *just touches* the glass plate. (This touching is to be tested by observing the coincidence of the tip of the screw with its inverted image formed below the glass plate). The final reading (R_2) of the circular scale is noted. From the records of the initial and final readings (R_1 and R_2 respectively) of the circular scale, the extra or additional number (n) of the circular divisions rotated, over and above the m number of complete rotations of the circular disc, are found out (rule to find n is given at the foot note marked with asterisks). Then the total number of circular scale divisions rotated will be, $x = (Nm + n)$.

(*vi*) The elevation or depression (h) of the spherical surface from the plane surface would be $h = x \times (l\ c.)$. This determination of h is to be repeated at least thrice and the mean value of h is to be taken.

(*vii*) The screw is then raised up and the three outer legs are pressed on a paper. The consecutive distance between the three points so obtained is measured by employing a divider and a mm. scale. The mean of these three distances gives the value of 'd'.

(*viii*) The radius (r) of curvature of the given spherical surface is obtained from the relation $r = \frac{d^2}{6h} + \frac{h}{2}$.

Experimental data :

(A) *Determination of the least count (l.c.) :—*

Value of each division of the linear scale $= s = \cdots$ mm.

No. of divisions on the circular disc $= N = \cdots$

Pitch of the screw $= p = \cdots$ mm.

Least count of the instrument $= l.c. = p/N = \cdots = \cdots$ mm.

Distance between the outer legs $= d = \dfrac{\cdots + \cdots + \cdots}{3} = \cdots$ cms.

(B) *Determination of h* (here the screw is moved downward and this downward movement decreases the circular scale reading) :—

[*Numerical figures given in the table are for illustrations only.*]

No. of Obs.	Initial C.S. reading when the screw touches the spherical surface (R_1)	When the screw touches the plate			Total no. of C.S.D. rotated $= x = Nm+n$	Values of these divisions in mm. $(h) = x \times (l.c.)$	Mean (h) in cm.	Radius of the surface is $r = \frac{d^2}{6h} + \frac{h}{2}$ in cm.
		No. of full rotation of cir. disc. (m).	Final cir. scale reading (R_2)	Add no. of C.S. divisions rotated (n)*				
1.	29	3	98	31	331	...		
2.	30	3	0	30	330	...	...	...
3.	29	3	99	30	330	...		

*N.B.(*a*) If the direction of movement of the screw (downward of upward) decreases the circular scale readings, then $n = [N - (R_2 - R_1)]$; when $R_2 > R_1$ and $n = (R_1 - R_2)$; when $R_2 < R_1$.

(*b*) If the direction of movement of the screw (downward or upward) increases the circular scale readings, then, $n = (R_2 - R_1)$; when $R_2 > R_1$
$n = [N - (R_1 - R_2)]$ when $(R_2 < R_1)$

Calculation :

$$r = \frac{d^2}{6h} + \frac{h}{2} = \cdots + \cdots = \cdots \text{cm.}$$

Precautions : (*i*) To touch the screw with the surface, it (the screw) should be lowered down always in one direction (to avoid backlash error) until the tip of the screw just touches the tip of its own image below the surface.

(*ii*) Three different readings should be taken by touching the screw to three different points of the surface.

(*b*) To measure the thickness of a plate :

Description of Spherometer :—Same as in the part (*a*).

Theory : [write item (*i*) only 'for spherometer' in Expt. 9(*a*)].

Procedure : (*i*) and (*ii*)—Same as the items (*i*) and (*ii*) of part (*a*).

(*iii*) The test plate (whose thickness is required) is put on a base plate (which is simply a plane glass plate) and the spherometer (whose central leg is already kept raised above the plane containing the tips of the three outer legs) is so placed that the tip of its raised central leg may remain above the test plate while the tips of its three outer legs touch the base plate. The disc D of the screw head is rotated clockwise, always *slowly and in one direction only*, until the screw-tip just touches the test plate. This touching is to be tested by observing the coincidence of the screw-tip with its inverted image (if any) formed below the surface of the test plate. The reading R_1 of the circular scale is noted.

(*iv*) The test plate is now removed. The screw-tip of the spherometer is now to be lowered down by rotating the circular disc D clockwise.

(*v*) Same as the operation (*v*) of part (*a*).

(*vi*) The thickness t of the test plate would then be given by, $t = x \times (l.c.)$. This determination of t should be repeated at least for five times by bringing the two surfaces of test plate in contact with the base plate alternately. The mean of these ten values of t will be thickness of the plate.

Experimental data :

(A) *Determination of the least count* (*l.c.*) :—

[Same as in the part (*a*)]

(B) *Determination of the thickness* (*t*) *of the plate* :—

[Make a table as in item (*B*) of the 'experimental data' of part (*a*), but write '*t*' for '*h*' and omit the last column.]

Precautions : [Same as in the part (a)].

10. Determination of the thickness of a given substance by slide callipers.

Description : Slide callipers is employed in measuring the thickness of a lens, or the length of a rod or the diameter of a cylinder.

It consists of nickel-plated thin steel scale, with a jaw J_1 fixed at right angle to one end. There is another jaw J_2 which can be moved over the steel scale S. A vernier scale V is fixed on this movable jaw. When jaws J_1 and J_2 touch each other there is no gap between them and the zero of the vernier coincides with zero of the scale. If the zero of the vernier does not coincide with the zero of the scale, when the gap between the jaws is nil, then an instrumental error will come in. The slide callipers is shown in Fig. **7**.

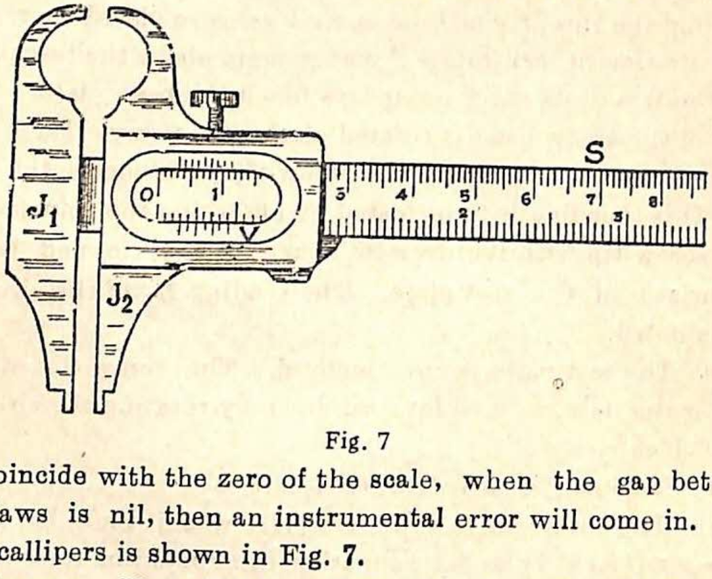

Fig. 7

Theory : If n divisions of the vernier scale coincide with $(n-1)$ divisions of the main scale then the value of one vernier division $(v.\ d.)$ is $n/(n-1)$. Hence vernier constant $(v.\ c.)$ is given by,

$$v.\ c. = 1\ s.\ d. - 1\ v.\ d. = \left(1 - \frac{n}{n-1}\right)\ s.\ d. = \frac{1}{n}\ s.\ d.$$

If for a given gap between the fixed jaw (J_1) and movable jaw (J_2) the readings of the scale and vernier are respectively S and $(v.r.)$ then the length of the gap between the two jaws is given by,

$$l = S + (v.r.) \times (v.\ c.) = S + V \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

$$[\text{where, } V = (v.\ r.) \times (v.\ c.)]$$

Procedure : (*i*) The value of the smallest division of the main scale as well as the total number of vernier scale divisions are noted. Then the number of smallest divisions of the scale which coincide with the total number of vernier divisions are found out and from this coincidence the **vernier constant,** (*v.c.*) *i.e.*, the length of the gap between one smallest division of the main scale and that of vernier division is determined.

(*ii*) The movable jaw is made to touch the fixed jaw and the readings of the main scale and vernier are noted which give the zero error of the instrument.

(*iii*) The movable jaw is then drawn out and the body whose thickness or diameter is required is placed in the gap between the two jaws. The movable jaw is then pushed in to touch the body and the readings of the scale (*S*) and vernier (*v.r.*) are noted. Value of vernier reading $(V) = (v\,r.) \times (v.c.)$.

(*iv*) The readings are repeated for several positions of the body and the mean of these readings when corrected for the instrumental or zero-error, if any, gives the required thickness or diameter of the body.

Experimental data :

Value of 1 small division of the main scale = 1 mm,
Total number of vernier divisions = 10

$$10 \text{ v.d.} = 9 \text{ s.d.} = 9 \text{ mm.} \qquad \therefore \; 1 \text{ v.d.} = \tfrac{9}{10} \text{ mm.}$$

Vernier constant $(v.c.) = (1 \text{ s.d.} - 1 \text{ v.d.}) = (1 - \tfrac{9}{10})$ mm. = ·01 cm.
Instrumental error = nil.

No. of Obs.	Reading in cm., of			Mean reading in cm.	Corrected reading in cm.
	Scale (S)	Vernier $(V) = (v.r.) \times (v\,c.)$	Total $= (S+V)$		
1.	....	...	...	...	...
2-	...	...	...	...	...
3.	...	....	...	...	...
4	...	...	...	...	...
5.	...	...	...	...	...

11. Balance and its adjustments.

Description : The complete figure of a balance is shown in Fig. 8.

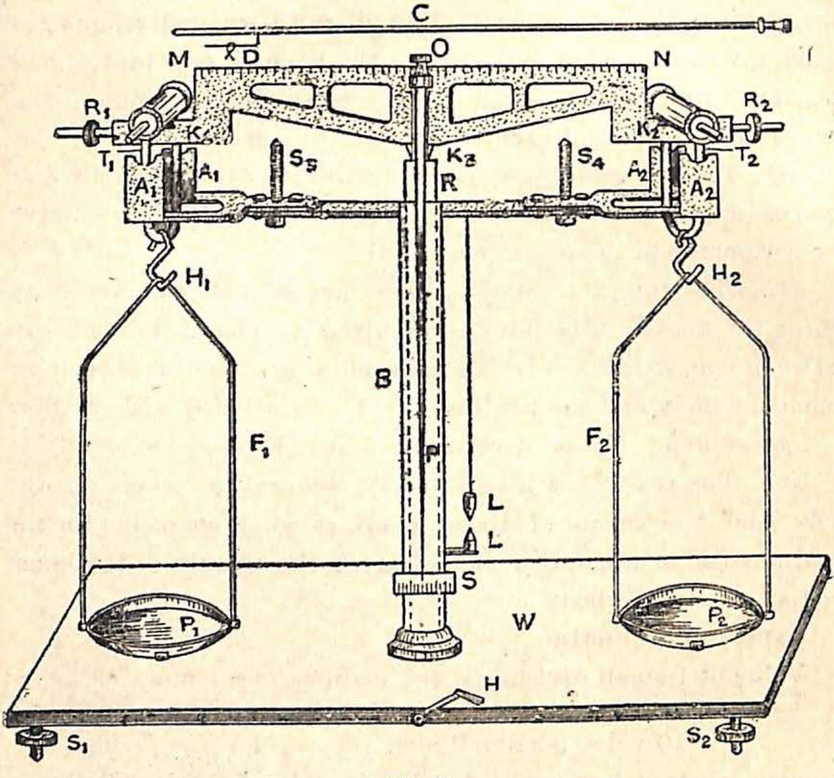

Fig. 8

W = Horizontal wooden base-board provided with levelling screws S_1 and S_2.

B = Pillar in which a rod *R* can be raised or lowered by a handle *H* fixed to the base *W*. On the top of the rod *R*, an agate plate is fixed.

MN = A metal beam at the middle of which there is an agate knife edge K_3 fixed with its sharp edge downwards. When the beam is free, the sharp edge of K_3, rests on the agate plate fixed on *R* and the weight of the beam passes through K_3, as a result the beam remains horizontal. A scale is marked on the upper edge of the beam *MN* so that on both sides of the zero mark at the centre there are 10 large divisions. Each large division is again subdivided into 5 or 10 small divisions.

D = A centigramme rider, which is kept suspended from a hook attached to the rider-carrier rod C. By moving this rod the rider can be placed on any mark of the scale. When the rider is placed on the mark 1 in the arm ON, then it is equivalent to the addition of 1 mg. on the pan P_2. As the distance between 0 and 1 is subdivided into 5 or 10 small divisions, we can increase the weight on each pan by steps of $\frac{1}{5}$th or $\frac{1}{10}$th of a mg.

R_1 & R_2 = Screw nuts at the two ends of the beam, by screwing which in or out, the turning moment on the side of the screw nut, can be respectively decreased or increased.

K_1 & K_2 = Two other agate knife-edges fixed at the ends of the beam with their sharp edges upwards. The distances K_3K_1 and K_3K_2 are equal and are known as the *arms of the beam.*

T_1 & T_2 = Two stirrups which rest on the knife-edges K_1 and K_2. The stirrups carry hooks H_1 and H_2 from which long rectangular frames F_1 and F_2, carrying pans P_1 and P_2 are respectively suspended. The sum of the weights of the stirrup, the rectangular frame and the scale pan on one side is equal to that on the other side.

P = Pointer fixed to the middle of the beam. The lower end of this pointer moves over an ivory scale S graduated from 0 to 20 from left to right [Fig. 8(a)].

A_1 & A_2 = Arrestors of stirrups T_1 and T_2. When the beam is lowered, the stirrups are arrested by A_1 and A_2 by which the knife-edges K_1 and K_2 are kept free from pressure.

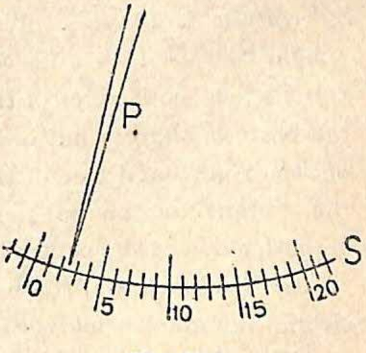

Fig. 8(a)

S_3 & S_4 = Screws fixed to the frame attached to the pillar so that the beam can rest on it when the balance is not in use. By this arrangement, the knife-edge K_3 is kept free from pressure when the rod R goes down.

L & L = Plumb line by which we can judge whether the pillar is vertical or not and this can be done by adjusting the levelling screws S_1 and S_2 at the base.

The whole thing is enclosed in a glass case provided with a glass window which can be opened and closed. The rider can be put on any mark of the beam by operating from outside.

Adjustments : (*i*) All dirts from the pan, if any, are to be brushed off by a clean cloth.

(*ii*) The stirrups supporting the scale pans are to be placed in their proper position, if there be any previous displacement of them.

(*iii*) The levelling screws at the base should be adjusted until the plumb line is vertical.

(*iv*) If necessary, one of the screw nuts at the ends of the beam should be adjusted until the pointer swings equally on both sides of the central line of the ivory scale.

(*v*) Body (which should not be too heavy) should be placed on the left-hand pan while standard weights from the weight box are to be placed on the right-hand pan (only when the beam is kept arrested) until the beam is horizontal.

Precautions : (*i*) At each time, *the balancing of the beam is to be tested by raising the beam a little by the handle and not by raising it in full.* When the beam is almost balanced, it should be raised in full to see whether the pointer swings equally on both sides of the central line of the ivory scale. If the beam is slightly out of balance, then the rider is to be put on the right-hand side of the beam at a proper mark to increase the weight on this pan, so that the pointer may swing equally on both sides of the central line.

(*ii*) Balancing of the beam is to be tested from outside, by closing the glass window to avoid air disturbances.

(*iii*) *A very heavy body, or a hot body, or a cold body should never be weighed in a physical balance.*

12. *To weigh a body by, (a) Equal-displacement method, (b) Oscillation method.*

(*a*) Weighing by equal displacement method :

Procedure and Principle : (*i*) At first the balance should be properly adjusted and the screw nuts at the two ends of the beam are to be shifted in or out until the pointer, during the course of its oscillation about the fulcrum K_3 (central knife edge), is displaced almost equally on both sides of the central line [line numbered 10 in Fig. 8(*a*)].

(*ii*) The body to be weighed is then to be placed on the left pan while suitable standard 'weights' from the weight box are to be placed on the right pan until the pointer again swings equally on both sides of the central line. If the lowest 'weight' available in the box cannot bring this equal displacements of the pointer then a centigramme rider should be placed at a suitable mark on the beam until the pointer swings equally on both sides of the central line of the scale. At this time, the weight of the body will be equal to the 'weights' placed on the right-hand pan.

When the pointer swings equally on both sides of the central line, the beam of the balance becomes horizontal. Consequently, the turning momets of the weights, at the two ends of the beam, about the central knife edge K_3 (which is the fulcrum) will be equal. That is,

weight of (P_1 pan + substance) × left arm = weight of (P_2 pan + weights) × right arm. If the two scale pans P_1 and P_2 are of equal weights and if the two arms are of equal lengths, i.e. $K_3 K_1 = K_3 K_2$, then the weight of the body will be equal to the 'weights' placed on the right pan. In other words, the mass of the body will be equal to the sum of the masses of the 'weights' on the right pan.

(*b*) Weighing by oscillation method :

Principle : When the beam of a balance is made free, the pointer continues to perform damped simple harmonic motion, with diminishing amplitude, for an appreciable time. Hence to save time, the resting point of the pointer should be determined by oscillation method. For this purpose, the extreme left-hand mark of the scale (over which the pointer moves) is to be considered as zero and the successive turning points of the pointer, *beginning from left*, are to be noted from the scale for *two complete oscillations* of the pointer (Fig. 9). This gives three readings of the pointer to the left and two readings to the right (Fig. 9). The mean of the three readings to the left as well the mean of the two readings to the right are to be determined separately. The mean of these two means will give the resting point of the pointer.

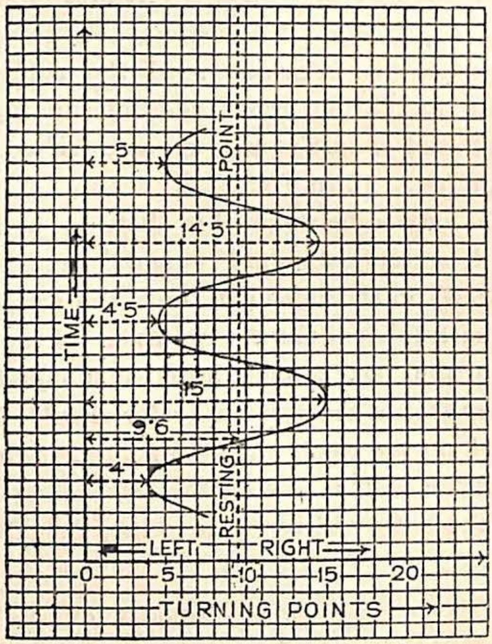

Fig. 9

Let P be the resting point of the pointer for an unloaded balance and Q be its resting point when the beam is almost balanced with the body on the left-hand pan and weights W_1 on the right-hand pan. The resting point R of the pointer is again determined with an extra load of value m mg, say (m may lie between 10 mg. and 2 mg.) added to the right-hand pan either directly from the weight box or by putting a rider on the right hand portion of the beam.

Thus, $(Q-R)$ divisions are the shift of the resting point by the addition of m mg. (say). Hence, $(Q-P)$ divisions shift of the resting point will be caused by, $\frac{Q-P}{Q-R} \times \frac{m}{1000}$ gms. Therefore the true weight of the body $W = W_1 + \frac{Q-P}{Q-R} \times \frac{m}{1000}$ gms. ··· (1)

Procedure : (*i*) The dust particles on the pan, if any, are brushed off by a clean cloth.

(*ii*) Stirrups are placed in their proper positions and the levelling screws at the base are adjusted until the plumb line is vertical.

(*iii*) The screw nuts at the ends of the beam are adjusted until the pointer swings almost equally on both sides of the central line of the ivory scale.

(*iv*) The resting point of the pointer is determined for an unloaded balance and this determination is repeated for three times. The mean of these three resting points is found out and let this mean value be P.

(*v*) Then by placing the body on the left-hand pan and suitable weights W_1 on the right hand pan, the resting point is again determined for three times. Let the mean value of these three resting points be Q.

(*vi*) By placing an additional weight of m mg. (here $m=10$ mg) on the right hand pan, the resting point of the pointer is also determined for three times. Let the mean of these three resting points be R.

(*vii*) The true weight (W) of the body is then calculated from the relation (1).

Experimental data :

[*The numerical figures in the table are for illustrations only*]

The scale reading at the extreme left is taken as zero.

No. of obs.	Load on left pan	Load on right pan	Turing points in *scale div.*		Mean of		Resting point in *s.d* $=\frac{m_1+m_2}{2}$	Mean resting point in *s.d.*
			left	right	three left (m_1)	two right (m_2)		
I	Nil	Nil	5 5 5·5	14 13·5	5·2	13·8	9·5	9·7 $=P$
			3·5 4 4	16 15·5	3·8	15·8	9·8	
			4·5 5 5	15 15	4·8	15	9·9	
II	Body	12 gm. $+500$ mg. $+50$ mg. $=12·55$ (W_1) gms.	7 7 7·5	18 17·5	7·2	17·8	12·5	12·2 $=Q$
			9 9 9·5	15 14·5	9·2	14·8	12	
			7 7 7·5	17 16·5	7·2	16·8	12	
III	Body	12·55 gm. $+10$ mg.	4 4 4·5	9 8·5	4·2	8·8	6·5	6·6 $=R$
			3 3 3·5	10 9·5	3·2	9·8	6·5	
			3·5 3·5 4·0	10 9·5	3·7	9·8	6·8	

Calculation :

$$W = 12{\cdot}55 + \frac{Q-P}{Q-R} \times \frac{10}{1000} = 12{\cdot}55 + \frac{12{\cdot}2 - 9{\cdot}7}{12{\cdot}2 - 6{\cdot}6} \times \frac{1}{100}$$

$$= 12{\cdot}55 + \frac{2{\cdot}5}{5{\cdot}6} \times \frac{1}{100} = 12{\cdot}55446 \text{ gms.}$$

Precautions : (*i*) The resting point P should be intermediate between the resting points Q and R.

[For other precautions, See Art. 11.]

13. To draw a graph showing the variation of sensitivity of a balance with loads.

Theory : Sensitivity of a balance is measured by the number of scale divisions by which the pointer is deflected when there is an excess load of 1 mg on the right pan over that on the left pan.

Suppose the beam $M'N'$ of the balance, having its arms $OM' = ON' = a$, is deflected by an angle θ by the addition of an excess load of magnitude w mg. on the right pan (Fig. 10). If $d (= PP')$ be the linear displacement of the pointer on the

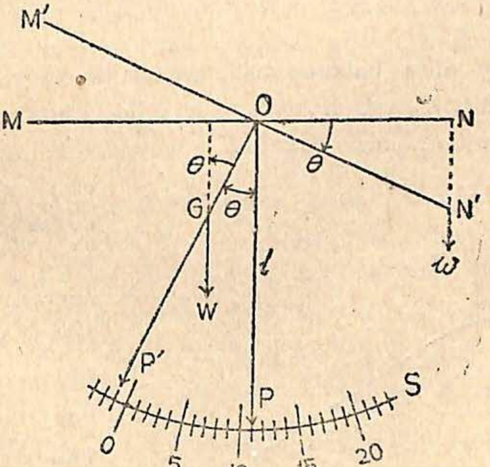

Fig. 10

circular scale S, then, $\theta = d/l$, where l is the length of the pointer. Let the whole weight of W gms. of the beam [$= 1000 \times W$ mg.] act at its centre of gravity G whose distance from the fulcrum O is $OG = h$. The moment of w about O is $wa \cos\theta$ while the moment of W about O is $1000\ Wh \sin\theta$.

For equilibrium of the beam,

$$1000Wh \sin\theta = wa \cos\theta, \quad \text{or,} \quad \tan\theta = \frac{wa}{1000Wh}.$$

As θ is small, $\tan\theta = \theta = d/l$. Hence, $\dfrac{d}{l} = \dfrac{wa}{1000Wh}$

$$\textbf{Sensitivity of the balance} = \frac{d}{w} = \frac{al}{1000Wh} \qquad \ldots \qquad \ldots \qquad (1)$$

Thus sensitivity can be increased by making the arms long (*i.e.* by making a long) by diminishing the weight W of the beam and by diminishing h, the distance between the fulcrum O and *c.g.* (G) of the beam.

Sensitivity of a balance becomes maximum when its three knife-edges (K_1, K_2 and K_3) are in one horizontal straight line. Usually the central knife-edge (K_3) remains below the plane of two extreme knife-edges (K_1 and K_2) and consequently sensitivity is now less than the maximum value. When equal loads on each pan are increased, the beam bends and lowers the positions of the two extreme knife-edges. As a result, sensitivity increases [Fig. 11]. when the loads on

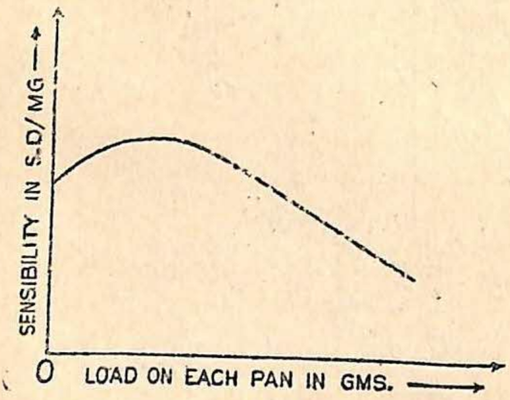

Fig. 11

the pan are sufficient to lower the plane of the extreme knife-edges below the central knife-edge (K_3), the sensitivity again decreases. The nature of this variation of the sensitivity of the balance with increasing loads is shown in Fig. 11, when the initial position of the central knife-edge is below the plane containing the two extreme knife-edges. If initially, K_3 remains above the plane of K_1 and K_2, sensitivity would decrease with loads.

Procedure : (*i*) At first the two pans of the balance are kept unloaded and the resting point of the pointer is determined by observing its turning points (begining from left) for two complete oscillations. This determination is repeated thrice and the mean resting point (P) is determined.

(*ii*) The resting point of the pointer is again determined thrice by putting an extra load of m mg. (m may lie between 2 and 10 mg.) on the right pan and the mean (Q) of these three resting points is again found out. The sensitivity of the balance for zero loads on the pans will be given by,

$$\frac{Q-P}{m}\ s.d./mg.$$

(*iii*) This determination of the mean resting point (mean of three resting points) of the pointer is repeated by placing an equal load of 10 gms. on each pan and again by putting an excess load of m mg. on the right pan. From these two mean resting points sensitivity of the balance for a load of 10 gms. is calculated in the manner as shown in operation (*ii*).

(*iv*) In this way, the sensitivity of the balance is found out for equal loads of 20, 30, 40, 50, 80, 100 and 150 gms. on each pan.

(*v*) A graph is then drawn with loads along x-axis and the corresponding sensitivity along y-axis. The nature of the graph will be of the type as shown in Fig. 11.

Experimental data :

No. of obs.	Load on left pan	Load on right pan	Turning points in *scale div.*		Mean of,		Resting point $=\frac{(m_1+m_2)}{2}$	Mean resting point	Sensitivity $=\frac{Q\sim P}{m}$ *s.d.* per mg
			left	right	three left (m_1)	two right (m_2)			
1			(*i*) ...						...
			...	...					
			....	...	...	...	...		
	0	0	(*ii*) ...					... $=P$	
			...	...					
			...	...	...	...	...		
			(*iii*) ..						
			...	...					
			...	...	...	...	...		
			(*i*) ...						
			...	...					
			...	...	...	...	...		
	0	m mg.	(*ii*) ...					... $=Q$	
			...	...					
			...	...	...	...	...		
			(*iii*) ...						
			...	...					
			...	...	...	...	...		
2			(*i*) ...						...
			...	...					
			...	...	...	...	...		
	10 gms.	10 gms.	(*ii*) ...					$=P$	
			...	...					
			...	...	....	...	...		
			(*iii*) ...						
			...	...					
			...	...	...	...	...		
			(*i*) ...						
			...	...					
			...	...	...	...	...		
	10 gms.	10 gms. + m mg	(*ii*) ...					.. $=Q$	
			...	...					
			...	...	...	...	...		
			(*iii*) ...						
			...	...					
			...	...	...	...	...		
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	

Oral Questions and their Answers

1. What is the distinction between mass and weight ? How do they vary ?

Mass (m) of a body is the quantity of matter contained in the body and it is an invariable quantity.

Weight (mg) of a body is the force with which the body is attracted by earth towards its centre. It varies from place to place. It decreases when the body is taken (*i*) at high altitude, (*ii*) in deep mine, (*iii*) from pole to equator. It vanishes at the centre of the earth. The variation of weight is due to the change of g, the acceleration due to gravity.

2. What are you measuring here,—mass or weight ?

Here we are getting the mass of body by comparing it with that of the standard 'weights'. Spring balance only will give the weight but not the common belance.

3. When will the beam of the balance be horizontal ?

The bean will remain horizontal when the moment of the weight of the body and that of the standared 'weights' about the fulcrum are equal.

4. What are the requisites of a good balance ?

The balance must be true, sensitive, stable and rigid (for details see any book of Physics).

5. What do you mean by the sensitivity of balance ?

[See theory of Expt. 13]

6. Why weights are placed on the right-hand pan and body on the left-hand pan ?

To weigh a given body the weights are to be varied and for convenience of putting weights, they are placed on the right-hand pan.

7. Is it desirable to put weights while the beam is free ?

No ; in that case the sharpness of knife-edges will be destroyed.

8. Why hot or cold body is brought to room temp, before weighing ? Incorrect weight will be obtained due to convection currents of air, if hot or cold body be weighed.

14. To read Fortin's barometer and to calculate atmospheric pressure.

Construction : (*i*) It consists of a thick-walled glass tube T of about a metre long, which is completely filled with pure, dry and air-free mercury and is inverted over a special type of cistern containing mercury [Fig. 12]. This tube T is enclosed vertically in a metal case C. A thermometer T_1 is attached to this metal case for noting the temperature of air.

(*ii*) Two diametrically oppposite slits are cut in the upper part of the brass case C at the place where the mercury in the tube T stands. On the two sides of this front slit, two scales S_1 and S_2 are marked, which are respectively graduated from 69 cms. to 83 cms. and 27 inches to 32 inches. The zeros of both these scales coincide with the tip of an ivory pointer P, fixed to the lid of the cistern. A vernier V can be moved by the sides of these scales by rack and pinion arrangement. A plane piece of brass, fixed to the vernier, moves with the vernier in the back slit.

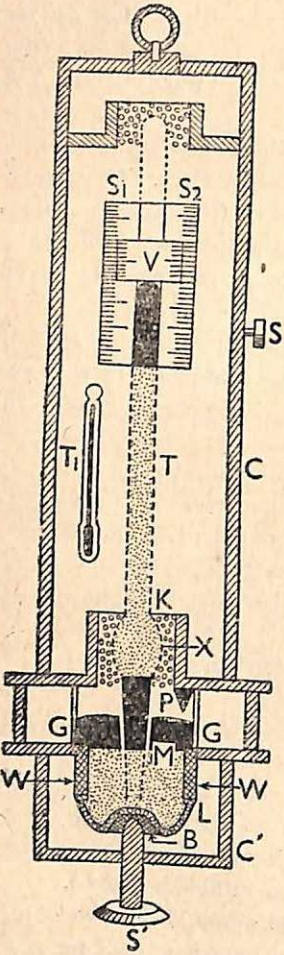

Fig. 12

(*iii*) The cistern of mercury consists of a glass cylinder G which is fixed to a wooden cylinder W. The bottom of this composite cylinder is closed by a leather sheet L, to the lower end of which a piece of wood B is fixed. This wooden piece B rests on a screw S', which can be operated from outside. The mouth of the cistern is closed by a porous leather K, through which air can exert pressure on the mercury surface. The tip of the ivory pointer P, fixed to the lid of the cistern, represents the zeros of the two scales S_1 and S_2.

Theory : The mercury column in the tube is supported by the pressure of atmosphere exerted on the free surface of the mercury in the cistern. Let H_t be the height of this mercury column at $t°C$. This height requires correction, for the true height will be obtained when both the brass scale and mercury are at 0°*C*. If α and γ are the co-efficients of linear expansion of brass and cubical expansion of mercury respectively then the correct height of barometer is given by, $H_0 = H_t (1 - \overline{\gamma - \alpha}\, t)$ ... ... (1)

If $\rho_0 (= 13{\cdot}596$ gms./c.c.) be the density of mercury at 0°*C*, and g ($= 978{\cdot}8$ cm./sec.^{2}) be the acceleration due to gravity then the atmospheric pressure is, $P = H_0 \rho_0 g$ dynes/sq. cm. ... (2)

Procedure : (*i*) The barometer tube is made vertical by a plumb line and the lower screw S' is adjusted (raised or lowered) until the mercury surface just touches the tip of the ivory pointer P.

(*ii*) The position of the vernier is adjusted until its (0 – 0) line, which is the lower edge of the vernier, becomes just tangential to the convex mercury surface in the tube T.

(*iii*) The vernier constants of both the verniers (one for cm. scale and another for inch scale) are determined and the readings of both the scales are noted corresponding to the zeros of the vernier. Thus we get H_t.

(*iv*) Knowing H_t, H_0 is calculated from (1) and putting this value of H_0 in (2) we get P, the atmospheric pressure in dynes per sq. cm.

Experimental data :

(A) *Temperature of air* :

Before experiment $= t_1 =$ ... °*C*.

After " $= t_2 =$ ... °*C*.

Mean temp. during expt. $= t°C = \left(\frac{t_1 + t_2}{2}\right)°C, = \ldots°C.$

(B) *Vernier constant determinations and noting the barometric height* :—

Centimetre Scale	**Inch Scale**
Smallest scale division = ···cm.	Smallest scale division = ···inch
···v.d. = ···s.d.	···v.d. = ···s.d.
1 v.d. = ···s.d.	1 v.d. = ···s.d.
v.c. = ··· = ···cm.	*v.c.* = ··· = ···inch

Scale	No. of obs.	Scale readings S	Vernier reading V $=(v.r.)\times(v.c.)$	Total reading $h=S+V$	Mean 'R'	Ratio $=\frac{\text{cms}}{\text{inches}}$
Centimetre	1.	75·8 cm.	$6\times\cdot01$ cm.	75·86 cm.	...cm.	...
	2.	... ,,	... ,,	... ,,		
	3.	... ,,	... ,,	... ,,		
Inch	1.	$29\frac{11}{16}$ inches	$\frac{7}{128}$ inches	$29\frac{95}{128}$ inches	... inches	
	2.	... ,,	... ,,	... ,,		
	3.	... ,,	... ,,	... ,,		

Calculations :

$\gamma = \cdot000182$ (from table)

$\alpha = \cdot000189$ (,,)

$\therefore\ H_0 = H_t\,(1-\overline{\gamma-\alpha}\,t) =$ ... = ... cms.

$P = H_0\rho_0 g = H_0 \times 13\cdot596 \times 978\cdot8 =$ ... dynes/sq. cm.

Precautions : (*i*) The barometer tube must be kept vertical.

(*ii*) Mercury surface in the cistern should *just touch* the tip of the ivory pointer.

(*iii*) Parallax should be avoided in taking the readings.

Oral Questions and their Answers

1. Why mercury and not water is employed in constructing barometer ?

As atmosphere supports a long column (34 feet) of lighter liquid water, the denser liquid mercury is preferable, for its height will be shorter and hence suitable for measurement in the laboratory. Also pressure of water vapour is greater than that of mercury.

2. Is the space above the mercury in the barometer vacuum ?

No ; it contains mercury vapour whose pressure is small. This space is called *Torricellian vacuum*.

3. Is the barometric height, an invariable quantity ?

No ; its height will decrease as we go to the higher altitude due to the decrease of the height of atmosphere. It also changes with the weather condition. The height will be greater in dry air than in moist air. The height will suddenly fall at the advent of storm.

4. Is it necessary that mercury should be dry ?

Yes ; otherwise water present in it will be vaporised and the pressure of this vapour will lower down the barometric height.

5. What is the practical usefulness of barometer ?

It is useful in ascertaining the condition of weather.

6. What is the harm if the barometer tube is kept inclined ?

If the barometer is kept inclined, the length of the column of mercury in the tube (which we actually measure) will increase though the vertical height of the column (which is not measured) will remain the same.

7. Does the barometric height depend on the cross-section of the tube ?—No, provided it is not too small.

15. *To determine the density of a given solid, soluble in water, by using a Sp. Gr. bottle.*

Apparatus required : (*i*) Sp. gr. bottle of 25 c.c. capacity ; (*ii*) A balance ; (*iii*) A weight box ; (*iv*) A liquid (usually kerosine oil) in which the solid is insoluble.

Theory : Sp. gr. of a substance is defined as the ratio of the weight of a certain volume of the substance to the weight of the same volume of water at 4°*C* ; while density of the substance is its mass per unit volume.

Let the weights of the,
bottle + water (at room temp. $t°C$) filling the bottle $= W_1$ gms.
empty bottle ... ... $= W_2$,,
bottle + granulated solid (filling about 1/3 of the bottle) $= W_3$,,
bottle + solid + insolvent liquid filling the bottle $= W_4$,,
bottle + insolvent liquid filling the bottle $= W_5$,,
Let the density of water at room temperature $t°C$. $= \rho_t$

Then Sp. gravity of the solid is given by*

$$\text{or,}\quad S = \frac{W_3 - W_2}{(W_5 - W_2) - (W_4 - W_3)} \times \frac{W_5 - W_2}{W_1 - W_2} \times \rho_t \quad \ldots \quad (1)$$

The density of the given solid is S gms. per c.c.

Procedure : (*i*) As the bottle supplied is usually *unclean* due to the presence of oil or any other impurities on the inside of it, the bottle should first be washed with dil. caustic soda, then with dil. nitric acid, and finally with the water for several times. As the bottle is wet with water, it is convenient to take the weight of water-filled bottle first. The bottle is then filled with tap water and after carefully introducing the stopper and wiping out any water on the outer surface of the bottle, it is weighed in a balance. Let this weight be W_1 gms.

(*ii*) The water is then thrown away and the bottle is washed with a little alcohol or methylated spirit or acetone and then dried by blowing hot air in it. The empty dry bottle with the stopper in it is then weighed. Let this weight be W_2 gms.

(*iii*) *About one third of the bottle* is then filled with the *granulated solid* (not powder) and weighed along with the stopper. Let this weight be W_3 gms.

(*iv*) The rest of the space above the solid is then filled with the insolvent liquid (usually kerosine oil) and it is weighed along with the stopper. Let this weight be W_4 gms.

(*v*) The solid and the liquid are then thrown away and the bottle is repeatedly washed with the insolvent liquid until the *last traces of the solid are removed.* The bottle is then filled with the insolvent liquid and after introducing the stopper it is weighed. Let this weight be W_5 gms.

(*vi*) The temperature $t°C.$ of the experimental water is noted by a thermometer and the density (ρ_t) in *c.g.s.* system, at this temperature is found out from a table.

---

*Weight of solid taken ... ... $=(W_3-W_2)$ gms.
Weight of insolvent liquid above solid $=(W_4-W_3)$,,
,, ,, ,, ,, filling the bottle $=(W_5-W_2)$,,
,, ,, water filling the bottle $=(W_1-W_2)$,,
,, ,, insolvent liquid of the same volume as solid
$=(W_5-W_2)-(W_4-W_3)$,,

S_1 = sp. gr. of solid with respect to insolvent liquid,

$$=\frac{W_3-W_2}{(W_5-W_2)-(W_4-W_3)}$$

$$S_2=\text{sp. gr. of insolvent liquid}=\frac{W_5-W_2}{W_1-W_2}$$

$$S=\text{sp.gr. of solid}=\frac{\text{wt. of } v. \text{ vol. of solid}}{\text{wt. of } v. \text{ vol. of insolvent liquid}}$$

$$\times\frac{\text{wt. of } v. \text{ vol of insolvent liq.}}{\text{wt. of } v. \text{ vol. of water at } t°C.}\times\frac{\text{wt. of } v. \text{ vol. of water at } t°C.}{\text{wt. of } v. \text{ vol. of water at } 4°C,}$$

or, $S=S_1\times S_2\times\rho_t$ [$\because \rho_t$, the density of water at $t°C.$ in c.g.s. system, is numerically equal to its sp. gr.]

$$\text{or, } S=\frac{W_3-W_2}{(W_5-W_2)-(W_4-W_3)}\times\frac{W_5-W_2}{W_1-W_2}\times\rho_t \quad \ldots \quad (1)$$

(*vii*) The experiment is repeated with the same bottle or with a different bottle by using a different amount of solid in the bottle. The sp. gr. is found out in each case by using the relation (1). The mean of the two specific gravities obtained from the two sets of observations will be the actual sp. gravity of the given solid.

Experimental data :

(*i*) Temp. of water taken $= t^\circ C = \ldots\ldots{}^\circ C$.

(*ii*) Sp. gr. of water at $t^\circ C = \rho_t = \ldots\ldots$

No. of Obs.	Wt. of bottle+ water W_1	Wt. of empty bottle W_2	Wt. of bottle+ solid W_3	Wt. of bottle+ solid+ K. oil W_4	Wt. of bottle+ K. oil W_5	Specific gravity (S)	Mean S
1.	...gm+ .. gm+ ...mg+... = gms	...gm+ gm+ ...mg+... = gms	...gm+ ...gm+ ...mg+... = gms	.. gm+ .. gm+ .. mg+... = ...gms	gm+ .. gm+ ...mg+... = gms	...	
2.						...	

N. B. [Details of the weights added are to be entered in the column. As for example, 15·236 gms. should be entered in the column as, 10 gms + 5gms + 200mg + 20mg + 10mg + 5mg + 1mg = 15·236gms.]

Calculations :

$$\text{Sp. gr.} = S = \frac{W_3 - W_2}{(W_5 - W_2) - (W_4 - W_3)} \times \frac{W_5 - W_2}{W_1 - W_2} \times \rho_t.$$

$$= \quad \ldots \quad \ldots \quad \ldots$$

Hence, density = ... gms./c.c.

Precautions : (*i*) During the introduction of the stopper in the bottle, care should be taken that no air bubble enters the bottle.

(*ii*) When the stopper is introduced into the bottle, some amount of liquid overflows and sticks to the outer surface of the bottle. The *liquid on the outer surface of the bottle should always be wiped out* by a dry blotting paper, before the bottle is weighed.

(*iii*) The solids introduced in the bottle should fill *at least one-third* of it and should be in the form of *fragments* so that difficulty may not arise during the time of their removal.

(*iv*) The bottle is to be held not by hand but always by a piece of paper so that the bottle may not be heated by the heat of the hand.

(*v*) All weighings are to be done by ordinary method and *not by oscillation method* for a little calculation will show that if the error in weighing be ±5 mg. the error in the final result is *not more* than 1%.

(*vi*) As it is necessary to clean the bottle first (for which water will be necessary for final washing) it is convenient to take the weight of water-filled bottle first.

16. *To determine the density of the given granular solid Insoluble in water, by using a Sp. Gr. bottle.*

Apparatus required : (*i*) Sp. gr. bottle of 25 c c. capacity ; (*ii*) a balance and an weight box and (*iii*) a thermometer.

Theory : Sp. gr. of a substance is defined as the ratio of the weight of a certain volume of the substance to the weight of the same volume of water at 4°C ; while density of the substance is its mass per unit volume.

Let the weights of the,

bottle + water (at room temp. $t^\circ C$) filling the bottle $= W_1$ gms.
empty bottle ... ... $= W_2$,,
bottle + granulated solid (filling about $\frac{1}{3}$ of bottle) $= W_3$,,
bottle + solid + water filling the bottle ... $= W_4$,,

Weight of solid taken ... $=(W_3 - W_2)$ gms.
,, ,, water above solid ... $=(W_4 - W_3)$,,
,, ,, ,, filling the bottle ... $=(W_1 - W_2)$,,
,, ,, ,, of same vol. as of solid $=(W_1 - W_2)-(W_4 - W_3)$,,

S_1 = sp. gr. of solid with respect to water at $t^\circ C$.

$$\text{or,}\quad S_1=\frac{W_3 - W_2}{(W_1 - W_2)-(W_4 - W_3)}$$

S = Sp. gr. of solid,

$$=\frac{\text{wt. of } v \text{ vol. of solid}}{\text{wt. of } v \text{ vol. of water at } t^\circ C}\times\frac{\text{wt. of } v \text{ vol. of water at } t^\circ C}{\text{wt. of } v \text{ vol. of water at } 4^\circ C}$$

$$=\frac{W_3 - W_2}{(W_1 - W_2)-(W_4 - W_3)}\times \rho_t \quad \ldots \quad (1)$$

where ρ_t is the sp. gr. of water at $t°C$ = density of water at $t°C$ in c g s. system.

The density of solid = S gms per c.c.

Procedure : (*i*) to (*iii*)—same as Expt. 15.

(*iv*) The rest of the space above the solid is filled with water at $t°C$ and again weighed. Let this weight be W_4 gms.

(*v* & *vi*)—same as in items (*vi*) and (*vii*) in Expt. 15.

Experimental data :

(*i*) Temp. of water taken = $t°C$ = ...°C.

(*ii*) Sp gr of water at $t°C = \rho_t = \cdots$

No. of Obs.	Wt. of bottle + water W_1	Wt of empty bottle W_2	Wt. of bottle + solid W_3	Wt. of bottle + solid + water W_4	Sp. gravity of the solid (S)	Mean S
1.	...gm + gm + mg + ... = . gms	...gm + ...gm + . mg + .. = gms.	gm + .. gm + ...mg + = ...g ms.	...gm + ...gm + ...mg + .. = . gms	...	...
2.						

N. B.—[As the bottle supplied usually contains oil or any other impurities it requires washing at the begining with caustic soda, dil, nitric acid and finally, with water. Hence it is convenient to take the weight of water-filled bottle first].

Calculation :

$$\text{Sp gr} = S = \frac{W_3 - W_2}{(W_1 - W_2) - (W_4 - W_3)} \times \rho_t = \quad \cdots \quad \cdots$$

Hence, density of solid = S gms per c c.

Precautions : [Same as in Expt. 15]

Oral Questions and their Answers

1 What is the distinction between density and sp. gr. and what are their units ?—See any text book of physics.

2. What do you measure here—density or sp. gr. ?

Sp. gravity ; but as sp. gr. and density are numerically equal in c.g.s. system we get, density = sp. gr. (gms/c c.)

3. Would you prefer powder or granulated solid ?

Granulated solid ; for air bubbles will always remain in powder and it becomes very difficult to remove the powders completely from the bottle.

4. Would you prefer small or large quantity of solid ?

. . A bit less than half of the bottle ; for small quantity gives smaller displaced liquid which brings large percentage error.

5. Why is the temp. of water noted ?

Sp. gr. is measured with respect to water at 4°C. When the sp. gr. with respect to water at $t°C$. is multiplied by the density (ρ_t) of water at $t°C$.) we get true sp. gr.

6. As the weight of a substance is not destroyed by solution. what harm is there if you take a solvent liquid ?

We do not get the weight of displaced liquid.

7. Are you getting here true weight ?—No ; to get correct weight, correction for the buoyancy of air is to be applied.

8. What is the density and sp. gr. of water ?

Density of water in *c.g.s.* and in *f.p.s.* systems are respectively 1 gm/c.c. and 62·5 lbs/cu. ft. Sp. gr. of water in both systems is 1.

17. To determine the Young's modulus of a wire by stretching.

(a) Vernier method.

Apparatus : It consists of two identical wires *AB* and *CD* of the same material and of the same cross-section, and they are suspended from the same support *AC*. The wire *CD* is loaded at its free end *D* by a fixed load *W* to keep it free from any kink. It carries a scale *S* whose smallest division is one *mm*. The experimental wire *AB* carries a vernier *V*, so that by the help of this vernier and the scale *S*, the elongation of the wire *AB* can be determined. The lower end of *AB* carries a hanger *H*, on which a fixed load is always kept which is known as the *dead load*. On this dead load, additional loads can be placed to elongate the wire *AB*. The arrangement is shown in Fig. 13.

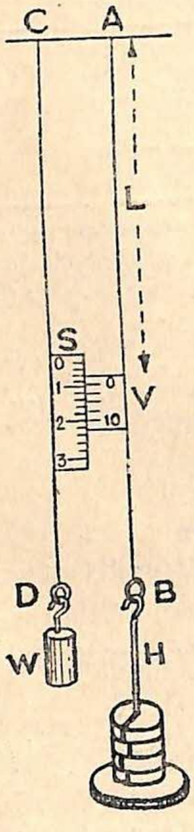

Fig. 13

Theory : If a wire be elongated by applying a load at its free end, then within elastic limit, the ratio of the longitudinal stress to the longitudinal strain is defined as the Young's modulus of the material of the wire.

Let the wire of length L cm. and diameter d cm. be elongated by l cm. by applying a load of M gms. at its free end, then,

$$\text{Longitudinal stress} = \frac{Mg}{\pi d^2/4} = \frac{4Mg}{\pi d^2};$$

$$\text{Longitudinal strain} = l/L.$$

$$\text{Young's modulus} = Y = \frac{4Mg}{\pi d^2} \times \frac{L}{l} = \frac{4Lg}{\pi d^2}\left(\frac{M}{l}\right) \text{ dynes/sq. cm.} \cdots\cdots(1)$$

Procedure : (*i*) By the help of a screw gauge the diameter of the wire AB is measured at various places (at least at five places) and at each place the diameter is measured in two directions at right angles to each other. The mean value of these diameters (d) and hence the cross-section $\pi d^2/4$ of the wire is determined [Table I].

(*ii*) The cross-section of the wire is multiplied by the breaking stress (supplied) of the material of the wire and this product gives the breaking load of the given wire. During experiment, the *maximum or limiting load on the hanger is kept below half of this breaking load.*

(*iii*) The length of the wire between the point of suspension and the point of the wire at which the vernier is fixed is measured thrice and its mean value (L) is found out.

(*iv*) The maximum permissible load, *i.e.* the limiting load is now put on the hanger for a few minutes to keep the wire taut. Then a greater part of the limiting load on the hanger is removed, leaving a certain portion known as the *dead load.* This dead load is sufficient to keep the wire free from any kink.

(*v*) The load which is removed from the hanger (*viz.*, limiting load—dead load) is divided into 6 or 7 equal instalments so that each instalment is either 1 kg. or ½ kg.

(*vi*) Additional loads (over and above the dead load) are now placed on the hanger by steps of 1 kg. or ½ kg. until the maximum permissible load is reached. At each stage, the readings of the scale and vernier are noted (Table II).

(*vii*) The loads are then decreased by steps of 1 kg. or $\frac{1}{2}$ kg. until the additional load on the hanger comes to zero and as before, the readings of the scale and the vernier at each stage are noted (Table II).

(*viii*) For each load, the mean of the two readings, one for the load increasing and another for the load decreasing, is determined from which the elongations of the wire for various loads are found out.

(*ix*) A graph is drawn with the additional load (in kilos.) along x-axis, while its corresponding elongation (in cm.) along y-axis, the origin being zero-zero. The graph will be a mean straight line passing through the origin. From this graph, elongation of the wire for a particular load (which is *not within the data*) is determined and this data regarding load and elongation (from graph) are employed to calculate Young's modulus from the formula (1).

Experimental data :

(A) *Diameter (d) of the wire :—*

Table I

[Make a Screw gauge chart as in Expt. 8 and take observations *at least* in 5 different places.]

(B) *Length (L) of the wire :—*

Distance between the point of suspension and the point of the wire at which the vernier is fixed is,

$$L=\frac{(i)\cdots+(ii)\cdots+(iii)\cdots}{3}=\cdots\text{cm.}$$

(C) *Breaking load of the wire :—*

Breaking load = Breaking stress $\times \pi d^2/4 =$ ... kg.

$\therefore$ Limiting load = Breaking load/2 = ... kg.

(D) *Recording of readings :—*

Value of one smallest scale division = ...mm.

...v.d. = ...s.d.

$\therefore$ $v.c.=\cdots$s.d. $=\cdots$mm. $=\cdots$cm.

TABLE II

Dead Load = 2kg.

No. of obs	Add. load in kilos	when *load increasing*, readings in cm. ; of			When *load decreasing*, readings in cm. ; of			Mean reading in cm. $=R=\frac{R_1+R_2}{2}$	Elongation in cm. (l)
		Scale (S)	Vernier (V) = ($v.r$) × (v c)	Total = R_1 = ($S+V$)	Scale (S)	Vernier (V) = ($v.r.$) × ($v.c.$)	Total = R_2 = ($S+V$)		
1	0	1·1	3×·01 = 03	1·13	1·1	5×·01 = ·05	1·15	1·14(a)	(a)−(a) = 0
2	1	1·1	9×·01 = ·09	1·19	1·2	0×·01 = ·00	1·20	1·195(b)	(b)−(a) = ·055
3	2	1·2	5×·01 = ·05	1·25	1·2	5×·01 = ·05	1·25	1·25(c)	(c)−(a) = ·110
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.
7	6	1·4	0×·01 = ·00	1·40	1·4	0×·01 = 00	1·40	1·40(g)	(g)−(a) = ·26

(E) *Drawing of the load-elongation graph* :—

To draw the load-elongation curve, the origins for both should be zero. Loads in kilos are to be plotted along x-axis (taking 10 small divisions as 1 kilo) while the corresponding elongations in cm. are to be plotted along y-axis. A number, slightly greater than the maximum value of the elongation in the data, should be found out and this number should be equally distributed amongst the total number of divisions available along y-axis. By plotting the various points, a straight line is drawn passing through the origin and the majority of points. If the straight line does not pass through all the points, then it should be drawn in such a way that the displaced points, are distributed on both sides of the straight line. If a point is far away from the line then that point should be rejected. Taking a suitable point (P, say) on the graph (the *co-ordinates of P should not be within the data*) the load in gms. (M) and the corresponding elongation in cm. (l) for this point are determined from which the value of Young's modulus (Y) of the wire is calculated from the formula (1). The nature of this curve, drawn from the following sample data of Table III, is shown in Fig. 14.

TABLE III

Add· load in Kilos→	0	1	2	3	4	5	6
Elongation (l) in cm.→	0	·055	·110	·145	·175	·225	·26

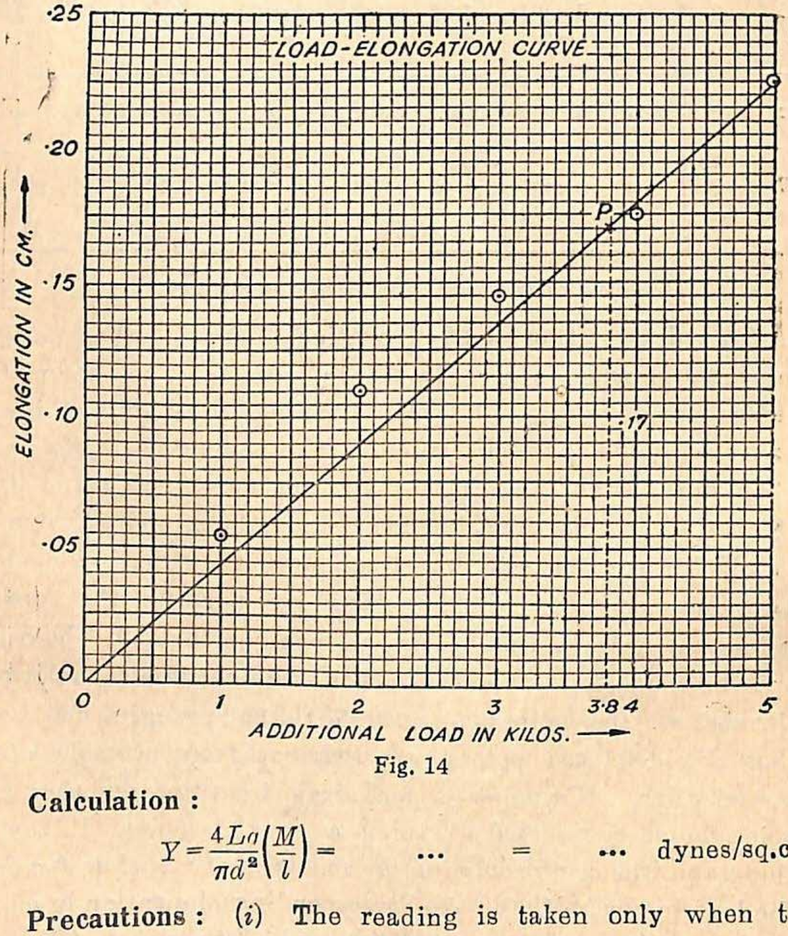

Fig. 14

Calculation :

$$Y=\frac{4Lg}{\pi d^2}\left(\frac{M}{l}\right)= \quad \dots \quad = \quad \dots \text{ dynes/sq.cm.}$$

Precautions : (i) The reading is taken only when the suspended system is steady and there is no twist in the wire.

(*ii*) Before putting the data in the formula, elongation (l), diameter (d) and length (L) should be converted to cm. while the load (M) should be converted to gms.

(*iii*) The dead load must be sufficient to keep the wire free from kink.

(*iv*) After adding a load to the hanger, reading is to be taken after waiting for some time so that the elongation of the wire is complete.

(*v*) The diameter of the wire should be measured at least at 5 different places and in each place along the two directions at right angles to each other.

Oral Questions and their Answers

1. Define, (*a*) Stress, (*b*) Strain, (*c*) Elastic limit and (*d*) Poisson's ratio.

(*a*) When a body is deformed by the application of a system of external forces (which are of course balanced by the internal reactionary forces), the deforming force per unit area of the body is known as the stress and its unit in c g.s. system is dynes per sq. cm.

(*b*) Strain is the fractional change of the deformation and as it represents the ratio of two similar quantities, it is a pure number.

(*c*) The range of deformation over which the body returns to its original state when the deforming forces are withdrawn, is called the elastic limit.

(*d*) The ratio of the lateral strain to the longitudinal strain is known as the Poisson's ratio (σ) and its value lies between $+\frac{1}{2}$ and -1.

2. Define Y and K and state the relation between them, What is the effect of temperature on them.

Young's modulus (Y) is the ratio of the longitudinal stress to the longitudinal strain and its unit in c.g.s. system is dynes per sq. cm.

Bulk modulus (K) of elasticity is the ratio of the volume stress to the volume strain and its unit is also dynes per sq. cm. in c.g.s. system.

The relation between Y, K and σ is given by $Y=3K(I-2\sigma)$.

both Y and K decrease with the rise of temperature.

3. What is the difference between breaking stress and breaking load ?

Breaking stress in gms.-wt. is the load in gms. required to break a wire of 1 sq. cm, in cross-section while breaking load for a wire is the load required to break the given wire. Thus breaking load = Breaking stress × cross-section of the wire.

4. Why do you determine the breaking load and why the limiting load is kept below half of the breaking load ?

Hooke's law is true within elastic limit and it has been found from the (stress-strain) diagram drawn up to the breaking point of the wire, that the maximum load for the elastic limit is nearly half of the breaking load. Hence the maximum load applied is kept below half of the breaking load.

5. Why two identical wires are taken ?

Scale and vernier are to be fixed to the two wires to measure elongation. Again the position of the vernier will not change with the change of temperature, if the two wires are identical.

6. Why are the wires suspended from the same support ?

To eliminate the change of reading due to the yielding of the support caused by the addition of load on the hanger only.

7. Will the Young's modulus change if you take wires of same material but of different diameters and lengths ?

No : for the change of length and diameter will cause a change in the elongation of the wire keeping Young's modulus (Y) constant.

8. What length of the wire you would measure and why ?

The distance between the point of suspension and the point of the wire at which the vernier is fixed is to be measured ; for the elongation of the wire below the point at which the vernier is kept fixed, will not cause any change in reading.

9. What quantity you would measure with great care ?

Diameter of the wire ; for it occurs in square power.

10. What will be the nature of the load-elongation graph ?

Within elastic limit the graph would be straight line passing through the origin.

11. Why dead load is necessary ?—To keep the wire free from any kink.

12. Why do you measure the diameter in two directions at right angles to each other ?

To avoid the error arising out of the elliptical cross-section of the wire.

13. Why do the readings for load increasing and decreasing differ ?

Due to elastic after-effect, the wire requires some time to regain its original length. Hence after the withdrawal of the load, the reading is usually greater.

(b) Micrometer method (Searle's apparatus)

Apparatus : The apparatus which is employed to find Young's modulus is shown in Fig. 15. It consists of two identical wires AB and CD whose upper ends are fixed on the same support AC attached to the ceiling. The lower ends of the wires carry the frame-works BB_1 and DD_1. These frame-works are joined by links L_1 and L_2 in such a way that they can move freely in a vertical plane. Inside the frame, there is a sensitive spirit level R fixed to a plane base. One end of this base is pivoted to a horizontal bracket fixed to the middle of the frame DD_1, while the other end of the base rests on the pointed end of a micrometer screw. The distance of the shift of the screw can be recorded from a vertical linear scale S and a circular scale S_1 marked on the disc fixed to the lower end of the screw. There are two hooks H_1 and H_2 attached respectively to the lower end of the frames DD_1 and BB_1. From the hook H_1 a fixed load W is suspended to keep the wire CD free from kink. To the hook H_2 a hanger H is attached, on which another fixed load called *dead load* is placed. On this dead load additional slotted loads can be placed to elongate the wire AB.

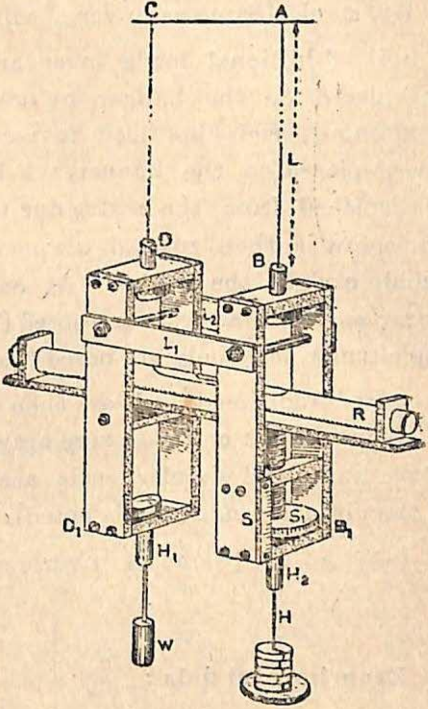

Fig. 15

Theory : [Same as in vernier method].

Procedure : (*i*) & (*ii*) [Same as in vernier method].

(*iii*) The length of the wire between the upper fixed point *A* and lower fixed end *B* is measured thrice and the mean of these three values gives the length *L* of the wire.

(*iv*) & (*v*) [Same as in vernier method].

(*vi*) Additional loads (over and above the dead load) are now placed on the hanger by steps of 1 kg. or $\frac{1}{2}$ kg. until the maximum permissible load is reached. At each time, as the load is placed on the hanger, the bubble of the spirit level will be displaced from the centre due to the elongation of the wire. The screw is then rotated *always in one direction* to bring the bubble back to the centre. At each step the readings of the linear and circular scale are noted (Table IIA) [or the reading of the circular scale only are noted (Table IIB)].

(*vii*) Additional loads are then decreased by the same steps as before until it comes to zero again. At each step, the readings of the linear and circular scale are again noted [or the reading of the circular scale only is noted].

(*viii*) & (*ix*) [Same as in vernier method].

Experimental data :

(A) *Determination of the diameter* (*d*) *of the wire* :—

TABLE I

[Make a screw gauge chart as in Expt. 8 and take observations *at least* in five different places].

(B) *Length* (*L*) *of the wire* :—

Distance between the point of suspension and the lower fixed end of the wire is,

$$L = \frac{(i) \quad + (ii) \quad + (iii) \ldots}{3} = \cdots \text{cm.}$$

(C) *Calculation of breaking load* :—

Breaking load = Breaking stress × $(\pi d^2/4)$ *kg.* = ⋯*kg.*

∴ Limiting load = Breaking load/2 = ...*kg.*

(D) *Recording of readings* :—

Smallest value of the linear scale $= s = \cdots$ mm.
Pitch of the screw $= p = \cdots$ mm.
No. of circular scale divisions $= N = \cdots$
Least count … $= l.c. = p/N = \cdots$ mm.
Or, $l.c. = \cdots$ mm. $= \cdots$ cm.

N. B. [In tables IIA & IIB the following values of s, p, N and $l.c.$ were taken for illustrations only ; $s = 1$ mm., $p = \cdot5$ mm. ; $N = 50$; $l.c. = \cdot5/50 = \cdot01$ mm.]

TABLE IIA (when readings of both *linear* and *circular scales* are considered).

Dead Load = 2Kg.

[Numerical figures in the table are for illustrations only].

No. of obs.	Addl. load in *kilos*	When *load increasing* readings in mm. : of			When *load decreasing*, readings in mm. : of			Mean reading in mm. $= R = \frac{R_1+R_2}{2}$	Elongation in mm.	Elongation in cm. (l)
		Linear scale (S)	Circular scale (C) $= (c.s.r.)(l.c.)$	Total $= R_1 = (S+C)$	Linear scale (S)	Circular scale (C) $= (c.s.r.)(l.c.)$	Total $= R_2 = (S+C)$			
1	0	5	47 × ·01	5·47	5	48 × ·01	5·48	5·475 (a)	(a) − (a) = 0	0
2	1	5	(50 + 24) × ·01	5·74	5	(50 + 25) × ·01	5·75	5 745 (b)	(b) − (a) = ·270	·027
3	2	6	7 × ·01	6·07	6	8 × ·01	6·08	6·075 (c)	(c) − (a) = ·600	060
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.
6	5	6	(50 + 45) × ·01	6·95	6	(50 + 48) × ·01	6·98	6·965 (f)	(f) − (a) = 1·490	·149
7	6	7	29 × ·01	7·29	7	29 × ·01	7·29	7·29 (g)	(g) − (a) = 1·815	·182

TABLE IIB (An alternative table when the *readings of circular scale only* are taken).

Dead Load = 2Kg.

[Numerical figures in the table are for illustrations only]

No. of steps	Addl. load in *kilos.*	Load *increasing*				Load *decreasing*				Mean of the two elongations *for the step.* in cm. $=\frac{x_1+x_2}{2}\times$ (*l c.*)	Total elongation in cm. *for the load* (l)
		C.S. reading at the *beginning of the step.* (R_1)	No. of complete rotations *for the step* (m)	C.S. reading at the *end of the step* (R_2)	Total no. of C.S.D. rotated *for the step.* $=x_1=Nm+n^*$	C.S. reading at the *end of the step.* (R_1)	No. of complete rotations *for the step.* (m)	C.S. reading at the *beginning of the step.* (R_2)	Total no. of C.S D. rotated *for the step.* $=x_2=Nm+n^*$		
1	0	47↓	nil ↓	47↓	0↓	48	nil	48	0	0	0
2	0	47	,,	24	27	25	,,	48	27	·027	·027
3	2	24	,,	7	33	8	,,	25	33	·033	·060
4	3	7	,,	37	30	36	,,	8	28	·029	·089
5	4	37	,,	11	24	17	,,	36	31	·028	·117
6	5	11	,,	45	34	48	,,	17	31	·033	·150
7	6	45	,,	29	34	29↑	,, ↑	48↑	31↑	·033	·183

(E) *Drawing of load-elongation graph* :—

[Same procedure as in vernier method].

Calculation :

$$Y=\frac{4Lg}{\pi d^2}\times\left(\frac{M}{l}\right)= \quad \cdots \quad = \quad \cdots\text{dynes/sq.cm.}$$

---

*N.B. [In the table, n = additional number of circular scale divisions rotated.

(*a*) When the direction of movement of the screw is such that the *rotation of its head increases the circular scale reading.*

$n=(R_2-R_1)$. when $R_2>R_1$,
$n=[N-(R_1-R_2)]$, when $R_1>R_2$,

(*b*) When the direction of mevement of the screw is such that the *rotation of its head decreases the circular scale reading.*

$n=[N-(R_2-R_1)]$ when $R_2>R_1$.
$n=(R_1-R_2)$ when $R_1>R_2$

Precautions : (*i*) to (*v*) [Same as in vernier method].

(*vi*) To avoid back-lash error in the reading, *the screw is* to be *turned always in the same direction* when a particular set of readings are noted.

Oral Questions and their Answers

1 to 12—[Same as in vernier method].

13. What is back-lash error and how would you avoid it ?

Usually the screw misfits into its nut and a small rotation of the head of the screw does not cause a corresponding linear movement. This defect of the screw is called *back-lash error*. It is eliminated by taking the readings by *rotating the screw always in the same direction.*

18. Determination of the rigidity of a wire by twisting it (Static method).

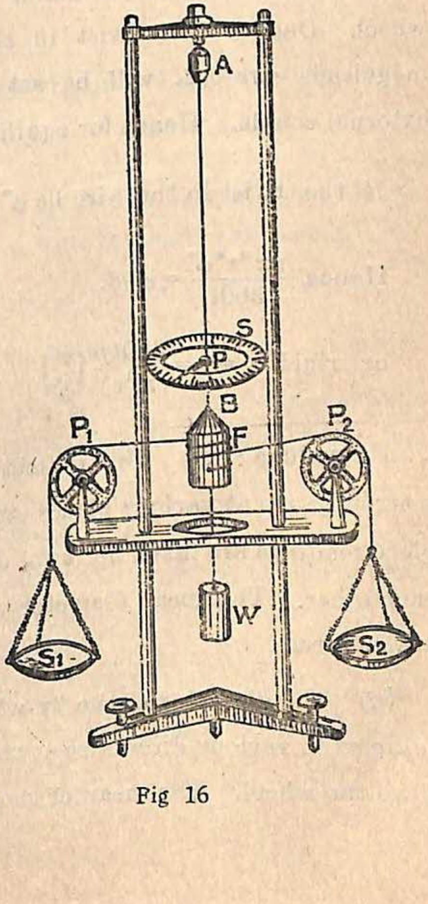

Fig 16

Apparatus : Various forms of rigidity apparatus are employed, one of which is described here.

The apparatus in the Fig. 16 consists of a rigid frame-work having a heavy iron base to which levelling screws are attached. The upper end *A* of the wire *AB*, whose rigidity is required, is attached to a suitable split chucks fixed to the top of the frame. The lower end *B* of the wire is attached to a fly-wheel *F* from which a heavy load *W* is kept suspended to keep the wire stretched. One end of each of the two cords is attached to a pin at the lower end of the fly-wheel F and then they are wound in the same direction. On reaching at the top of the fly-wheel, the cords leave the opposite extremity of a diameter and after passing over the pulleys P_1 and P_2, their free ends are attached to two scale pans S_1 and S_2 respectively. Equal loads can be placed on these pans to exert a twisting couple at the lower end of wire. The twist in the wire can be noted by a pointer P moving over a circular scale S graduated in degrees.

Theory : Let the lower end of a wire of length l and radius r be twisted by an angle of θ radian by the application of an external couple of moment mgd, where mg is the weight of the mass m placed on *each* pan and d is the diameter of the fly-wheel. Due to this twist in the wire, an internal couple of magnitude $n\pi r^4\theta/2l$ will be set up which will balance the external couple. Hence for equilibrium, $n\pi r^4\theta/2l = mgd$.

If the twist in the wire be ϕ°, then $\phi^\circ = \dfrac{\pi\phi^\circ}{180}$ radian.

Hence, $\dfrac{n\pi^2 r^4\phi^\circ}{360l} = mgd$.

$$\text{or, rigidity} = n = \frac{360lgd}{\pi^2 r^4}\left(\frac{m}{\phi^\circ}\right) \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Procedure : (*i*) The diameter of the wire is measured by a screw gauge at various places (at least in 6 places) and at each place readings are taken in two directions at right angles to each other. The mean diameter when halved gives the radius r of the wire.

(*ii*) The diameter of the fly-wheel is measured by a slide callipers in various directions at the place where the two strings elave the wheel. The mean of these readings gives d.

(*iii*) The length of the wire from the upper fixed point to the position of the pointer is measured by a scale. The mean of three such measurements gives l.

(*iv*) Various equal loads are placed on the two pans and at each time the reading of the pointer on the circular scale is noted. Readings for both increasing and decreasing loads are noted and from the mean of these two readings the twist in the wire for each load is determined.

(*v*) A graph is then drawn with loads as abscissa and the corresponding angles of twist in degrees as ordinate. The graph is a straight line passing through the origin, which is $(0-0)$. From the graph, the twist ϕ° for a particular load of m gms. is determined. Putting these value of m, ϕ, r, d and l in the relation (1), rigidity n is calculated.

Experimental data :

(A) *Measurement of the diameter* **(2*r*)** *of the wire :—*

Table I

[Make a screw gauge chart as in Expt. 8 and measure diameters in perpendicular direction *at least* in 6 different places.]

(B) *Determination of the diameter* **(*d*)** *of the fly-wheel :—*

Table II

[Make a slide callipers chart as in Expt. 10 and measure diameter at least in 4 different directions at the place where the strings leave the fly-wheel.]

(C) *Measurement of the length* **(*l*)** *of the wire :—*

The distance of the wire between the upper fixed point and the point where the pointer is fixed is,

$$l=\frac{(i)\cdots+(ii)\cdots+(iii)\cdots}{3}= \quad \cdots \quad = \quad \cdots \text{ cm.}$$

(D) *Determination of the twist* (ϕ°) *of the wire for various loads* (m) *:—*

Table III

No. of obs.	Load on each pan in gms.	Readings of the pointer in degrees					Twist in degrees
		Load increasing		Load decreasing		mean	
		End I	End II	End I	End II		
1	0	...	...	...	...	...(a)	(a) − (a) = 0
2	...	...	...	...	...	...(b)	(b) − (a) = ...
3	...	...	...	...	....	...(c)	(c) − (a) = ..
4	...	...	...	...	...	...(d)	(d) − (a) = ...
5	....	....	...	...	...	...(e)	(e) − (a) = ...
6	....	...	....	...	...	...(f)	(f) − (a) = ...
7	...	...	...	...	...	...(g)	(g) − (a) = ...

(E) *Drawing of $(m-\phi)$ graph :—*

To draw the load-twist curve, the origins for both are to be taken as zero. The loads (m) in gms. should be plotted along x-axis while the corresponding twist (ϕ°) in degrees should be plotted along the y-axis. By plotting the various points, a mean straight line is drawn passing through the origin and the majority of points. The other points, if displaced from the straight line, should not be far away from it. The nature of this straight line graph will be of the same type as the load-elongation curve shown in Fig. 14. Taking a particular point on the straight line (*which is not within the data*) the load (m) in gms. and the twist (ϕ°) in degrees corresponding to this point are determined from the graph. By putting the co-ordinates (m, ϕ°) of this point in the formula (1) along with the other data, the value of rigidity (n) is calculated.

Calculation :

Formula employed is,

$$n = \frac{360\ lgd}{\pi^2 r^4}\left(\frac{m}{\phi^\circ}\right) = \quad \cdots \quad = \quad \cdots \text{ dynes/sq. cm.}$$

Precautions : (*i*) After adding a certain load to the scale pans readings of the pointer are to be taken after waiting a little, so that the system may be steady.

(*ii*) As radius r occurs in 4th power, it should be measured very carefully otherwise a small error in the measurement of r will increase the error in the determination of n by 4 times. For this purpose, the diameter should be measured at least in 6 different places and at each place in two directions at right angles to each other.

(*iii*) The diameter of the fly wheel should be measured at the place, where the two strings leave the wheel and at this place that diameter should be measured at least in 4 different directions.

(*iv*) Care should be taken to maintain the strings, leaving the fly-wheel horizontal otherwise the arm of the couple applied will not be equal to the diameter of the fly-wheel.

Oral Questions and their Answers

1. Define rigidity and state its unit.

It is the ratio of shearing stress to shearing strain. As stress is the force per unit area while strain is the displacement gradient (having no unit), the unit of rigidity in c.g.s, system is dynes per sq. cm.

2. The formula for rigidity involves length and radius of the wire, how do they influence rigidity ?

They have no influence on rigidity. The change of length and diameter of the wire will cause a change of twist and not rigidity.

3. Which quantity you would measure very accurately and why ?

The radius of the wire should be measured very accurately for it occurs in 4th power.

4. How rigidity (n) is related to Young's modulus (Y) ?

$Y=2n\ (1+\sigma)$ where σ is the Poisson's ratio.

5. What is the effect of increase of temperature on the rigidity of the wire ?

Rigidity decreases with the increase of temperature.

6. What is the harm if the strings leaving the fly-wheel are not horizontal ? [See precaution (*iv*)].

7. At what place of your fly wheel you would measure its diameter and why ?

At the place where the strings leave the wheel, for the diameter of the wheel at that place is the arm of couple applied.

(*v*) A vertical line N is marked on the surface of the cylinder (when it is at rest). To find the period of its oscillation, either a pointer is to be kept fixed with its pointed end facing the vertical line N or a telescope is to be focussed from a distance on the vertical line N on the cylinder so that it may remain coincident (without any parallax) with the vertical line of the cross-wire of telescope. The cylinder is then twisted by a certain angle and is released to perform torsional oscillations about the vertical axis. The pendulum oscillation (if any) should be stopped. When the vertical line N on the cylinder is going towards right, by crossing the tip of the pointer or the vertical line of the cross-wire of the telescope, a stop-clock is started. The cylinder will perform one complete oscillation when the vertical line N on it, is for the next time crossing the tip of the pointer or the vertical line of the cross-wire of the telescope and is moving towards right. The stop-clock is stopped when the cylinder performs such 30 complete oscillations. This time for 30 complete oscillations is noted thrice independently and the mean of this time when divided by 30, we get the period (T) of oscillation of the cylinder.

(*vi*) The value of the rigidity n is then calculated by putting the values of I, l, r and T in the relation (4).

Experimental data :

(A) *Determination of the moment of inertia* (I) *of the suspended cylinder :—*

(*i*) Mass of the cylinder $= M =$ ... ... gms.

(*ii*) Diameter (D) of the cylinder.—

TABLE I

[Make a chart for slide callipers as in Expt. 10 and measure diameter in perpendicular directions *at least* in six different places.]

(*iii*) Calculation of (I), $I = \frac{1}{2}MR^2 = \frac{1}{2}M\left(\frac{D}{2}\right)^2 = \ldots = \ldots$ gm.-cm.^{2}

(B) *Length (l) of the suspension wire from its point of suspension to the point where the cylinder is attached.*

$$l=\frac{\cdots+\cdots+\cdots}{3}= \quad \ldots \quad \ldots \text{ cm.}$$

(C) *Measurement of the diameter ($d=2r$) of the wire :—*

Table II

[Make a screw gauge chart, as in Expt. 8, and measure diameters in perpendicular directions at least in eight different places.]

(D) *Determination of the period (T) of torsional oscillation of the cylinder :—*

No. of obs.	Time of 30 oscillations	Mean time	Period T in secs.
1.	... min. .... secs.	... min. ... secs.	... secs.
2.	... min. .... secs.		
3.	... min. ... secs.		

Calculation :

$$n=\frac{8\pi Il}{T^2r^4}= \quad \ldots \quad = \quad \ldots \text{ dynes/sq. cm.}$$

Precautions : (*i*) The pendulum oscillation of the cylinder (if any) should be stopped.

(*ii*) Care is to be taken to see that the suspension wire may coincide with the axis of the cylinder.

(*iii*) The radius r of the suspension wire occurs in 4th power and hence it should be measured very carefully otherwise a small error in the measurement of r will increase the error in the determination of n by four times.

(*iv*) The period (T) of oscillation should also be measured very carefully for it occurs in the second power in the expression of n.

Oral Questions and their Answers

1—5. (Same as in the Expt. 18).

6. Does the period of oscillation depend on the amplitude of oscillation of the cylinder ?

No : the angle of oscillation may have any value within the limits of elasticity of the suspension wire.

7. What is the difference between simple rigidity and torsional rigidity ? [See Q. 9. at the end of Expt. 18]

8. How will the period of oscillation of a torsional pendulum be affected when the length and diameter of the suspension wire is increased ?

Period will increase with the increase of length of the suspension wire but it (period) will decrease with the increase in the diameter of the wire.

9. How will the period of oscillation be affected if the bob of the pendulum be made heavy ?

If the mass of the bob be made greater, its moment of inertia I will be greater and hence it will oscillate slowly with greater period.

10. Will the period be affected by the change in the acceleration due to gravity ?— No.

20. *To determine the moment of inertia of a body about an axis passing through its centre of gravity and perpendicular to its length.*

Apparatus : The moment of inertia table (Fig. 18), which may be employed for this purpose, consists of a flat circular metal disc D having a concentric circular groove on its surface. This groove contains several masses 'm' by moving which in the groove the bubbles of the spirit levels L_1 and L_2, kept along the two perpendicular diameters of the disc, are brought at the centre. This circular disc is attached to a frame-work F. This frame-work with the disc, is kept suspended by a wire W in such a way that the disc D is horizontal (which can be tested by the spirit levels L_1 and L_2). A mirror R is fixed to the wire W, by which the period of oscillation of the disc can be noted by telescope and scale arrangement, if necessary. The whole apparatus is kept enclosed in a glass case to protect it from wind disturbances. By this arrangement the moment of inertia of a body about an axis passing through its centre of gravity may be determined.

The body (whose moment of inertia is known or unknown) is to be placed on the disc in such a way that the vertical axis of rotation of the disc passes through the c. g. of the body.

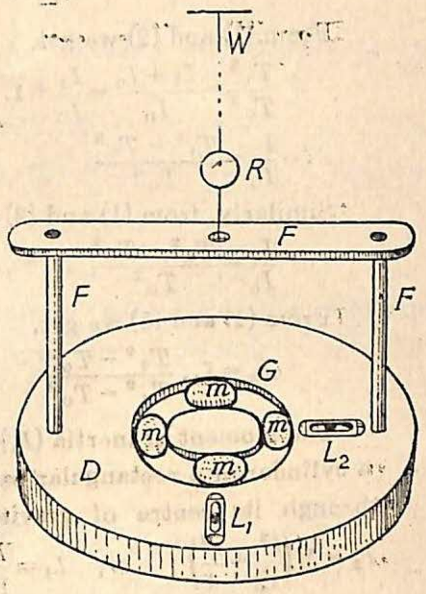

Fig. 18

Theory : The period T, of the torsional oscillation of a body of a moment of inertia I is given by, $T=2\pi\sqrt{\frac{I}{c}}$, where c is the torsional couple for 1 radian twist in the suspension wire.

If the period of oscillation about the vertical axis,

of the cradle alone ... ... $= T_0$.

of the cradle and the body of known moment of inertia $= T_1$,

of the cradle and the body of unknown moment of inertia $= T_2$

then,

$$T_0 = 2\pi\sqrt{\frac{I_0}{c}} \quad \cdots \quad \cdots \quad \cdots \quad (1)$$

$$T_1 = 2\pi\sqrt{\frac{I_1 + I_0}{c}} \quad \cdots \quad \cdots \quad \cdots \quad (2)$$

$$T_2 = 2\pi\sqrt{\frac{I_2 + I_0}{c}} \quad \cdots \quad \cdots \quad \cdots \quad (3)$$

where, $I_0 = M.I.$ of the cradle.

$I_1 =$,, ,, known body

$I_2 =$,, ,, unknown body.

From (1) and (2) we get,

$$\frac{T_1^2}{T_0^2} = \frac{I_1 + I_0}{I_0} = \frac{I_1}{I_0} + 1.$$

$$\therefore \quad \frac{I_1}{I_0} = \frac{T_1^2 - T_0^2}{T_0^2} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

Similarly, from (1) and (3) we get,

$$\frac{I_2}{I_0} = \frac{T_2^2 - T_0^2}{T_0^2} \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

From (4) and (5) we get,

$$I_2 = I_1 . \frac{T_2^2 - T_0^2}{T_1^2 - T_0^2} \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

The moment of inertia (I_1) of the known body (which may be a cylinder or a rectangular bar) about the vertical axis passing through its centre of gravity is calculated from the formula,

$$I_1 = M\left(\frac{l^2}{12} + \frac{r^2}{4}\right); \quad or, \quad I_1 = \frac{M}{12}(l^2 + b^2) \quad \ldots \quad \ldots \quad (7)$$

Here M, l, b and r represent the mass, length, breadth and radius of the known body respectively.

Procedure : (*i*) The mass (M) of the known body is determined by a rough balance or, spring balance while its diameter ($2r$) or breadth (b) and length (l) are measured by a slide callipers and ordinary metre scale respectively. Its moment of inertia (I_1) is then calculated from the relation (7).

(*ii*) The cradle alone is made to perform torsional oscillations with a *small amplitude* and the time for 30 oscillations is noted thrice. The mean of these three observed times when divided by 30, we get the period (T_0) of the cradle.

(*iii*) The known body is then placed horizontally on the cradle and the period of oscillation (T_1) of the cradle and the known body together is determined as before.

(*iv*) The known body is then replaced by the unknown body and the period of oscillation (T_2) of the cradle and the unknown body together, is similarly determined.

(*v*) Putting the values of I_1, T_0, T_1 and T_2, in the formula (6), the moment of inertia I_2, of the unknown body is calculated.

Experimental data :

(A) *Determination of the moment of inertia of the known body* :—

(*i*) Mass of the known body, $(M) = \cdots\cdots$gms.

(*ii*) Length of the body, $(l) = \dfrac{(i)\cdots + (ii)\cdots + (iii)\cdots}{3} = \cdots$cms.

(*iii*) Diameter or breadth of the body—

TABLE I

[Make a chart for slide callipers as in Expt. 10 and measure diameter or breadth *at least* in 4 different places].

(*iv*) Calculation of I_1—

$$I_1 = M\left(\frac{l^2}{12} + \frac{r^2}{4}\right) = \quad \cdots = gm.\text{-}cm^2.$$

$$or,\quad I_1 = \frac{M}{12}(l^2 + b^2) = \cdots \text{gm.} - \text{cm}^2.$$

(B) *Determination of the periods of oscillation.*—

TABLE II

Oscillating body	Time for 30 oscillations	Mean time	Period in Seconds
Cradle	... min. ... sec. ... min. ... sec. ... min. ... sec.	... min. ... sec.	... $= T_0$
Cradle+ known body	... min. ... sec. ... min. ... sec. ... min. ... sec.	... min. ... sec.	... $= T_1$
Cradle+ unknown body	.... min. ... sec. ... min. ... sec. ... min. ... sec.	... min. ... sec.	... $= T_2$

Calculation :

$$I_2 = I_1 \cdot \frac{T_2^{\,2} - T_0^{\,2}}{T_1^{\,2} - T_0^{\,2}} = \quad \cdots \quad = \quad \cdots \quad = \quad \text{gm.-cm.}^2$$

Precautions : (*i*) The amplitude of oscillation should be kept small, so that the period may be independent of amplitude.

(*ii*) Pendulum oscillation is to be prevented by avoiding any oscillation of the suspension wire.

(*iii*) Care is to be taken to see that the axis of oscillation passes through the c.g. of the rod.

Oral Questions and their Answers

1. Define moment of inertia and radius of gyration and state the unit of moment of inertia.

The moment of inertia of a *particle* of mass '*m*' situated at a distance *k* from the axis of rotation is mk^2. The moment of inertia of a *body* about an axis is the product of the mass (M) and square of the radius of gyration (K) of the body. The radius of gyration (K) of the body is the distance of a point in the body from the axis of rotation so that if a particle of mass M, equal to the mass of the body, be kept at that point, then the particle will have the same moment of inertia as the given body. The unit of moment of inertia in c.g.s. system is ($gm.\text{-}cm.^2$).

2. Does the moment of inertia of the body depend on its axis of rotation ?

Yes : moment of inertia (MK^2) of a body will be different for its different axes ; for though the mass (M) of the body is remaining constant, the radius of gyration (K) will be different for different axes.

3. How do the pendulum and torsional oscillations differ ?

Pendulum oscillation is controlled by gravity while torsional oscillation is controlled by the torsional couple in the suspension wire.

4. What factors govern the period of torsional oscillation ?

The period of torsional oscillation is given by

$$T = 2\pi\sqrt{\frac{I}{c}}. \qquad \text{or,} \quad T = 2\pi\sqrt{\frac{2Il}{n\pi r^4}}.$$

Hence period T depends (*i*) rigidity (n), (*ii*) radius (r), (*iii*) length (l) of the suspension wire and also (*iv*) on the moment of inertia (I) of the oscillating body.

5. How would you proceed to know whether the moment of inertia so obtained is about the axis passing through the c.g. of the rod or not ?

At first the moment of inertia of the rod is to be determined by making the axis of rotation (which coincides with the suspension wire) to pass through the c.g. of the rod found by guess-work. Then the moment of inertia of the same rod is to be determined when the axis of rotation passing through two other points which are situated on both sides of the suspected c.g. The lowest of these three values of the moment of inertia so obtained will be the moment of inertia of the rod about the axis passing through its c.g.

21. To verify Boyle's Law for pressures above and below one atmosphere and to draw (P-V) curve.

Apparatus : Boyle's law apparatus is shown in Fig. 19. It consists of two wide glass tubes *AB* and *CD* which can be raised or lowered or can be clamped at any position of two uprights *RQ* and *ML* respectively. The upper end of *AB* is either closed or provided with a stop-cock *S*, while both the ends of *CD* are open. The lower open ends of the tubes *AB* and *CD* are joined by a thick-walled rubber tube *BED*. The whole of the rubber tube and parts of the tubes *AB* and *CD* are filled with pure and dry mercury. The tube *AB* is usually kept ungraduated but sometimes it is kept graduated in c.c. from above. Dry gas is enclosed in the space above the mercury surface in *AB*. A vertical scale S_1S_2 is fixed between the tubes *AB* and *CD* to measure the difference of mercury levels in them.

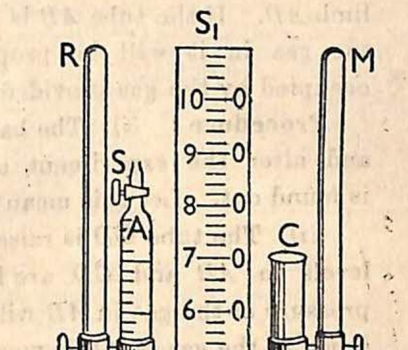

Fig. 19

Theory : Boyle's law states that *at constant temperature (T), the volume (V) of a given mass of a gas is inversely proportional to its pressure (P).*

Thus $P \propto 1/V$ when T is constant. If $P_1, V_1, ; P_2, V_2$;

P_3, V_3 ; etc. are the pressures and volumes of the same mass of a gas at different stages under constant temperature, then $P_1V_1 = P_2V_2 = P_3V_3 =$ etc.

If H cms. be the barometric height and h cms. be the difference of mercury levels in the open and closed limbs then the pressure of the gas enclosed in AB is $P = (H \pm h)$ cms. of mercury; + or − sign should be taken according as the mercury level in the open limb CD is higher or lower than that in the closed limb AB. If the tube AB is not graduated, then the volume of the gas in it will be proportional to the length of the tube occupied by the gas provided the *tube is uniform.*

Procedure : (*i*) The barometric heights are noted before and after the experiment and the mean of these two heights is found out. Let this mean height be H cms. of mercury.

(*ii*) The tube CD is raised or lowered until the mercury levels in AB and CD are in the same horizontal plane, when pressure of the gas in AB will be H cms. of mercury. The length l *cms.* of the gas in AB is measured by the scale S_1S_2 [or when the tube AB is graduated, the volume V c.c. of the gas in it is noted]. The product, Hl [or HV] is found out.

(*iii*) The tube CD is now raised in three or four steps, to diminish the length of the gas in AB, so that the length (l_g) of the gas at each step is less than that at its preceding step by about 1 or 2 cms. [or the volume (V_g) of the gas at each step is less than that at its preceding step by about 1 or 2 c.c.]. The difference of mercury levels (h cms.) in AB and CD is noted at each step, from which the gas pressure P_g $(= H + h)$ is found out. In all these cases, the product $(P_g \times l_g)$ [or $P_g \times V_g$] was found to be the same as $H.l.$ (or $H.V$). This verifies Boyle's law for pressures greater than one atmosphere.

(*iv*) The tube CD is now lowered in three or four steps, from the horizontal condition of mercury levels in AB and CD, so that the length (l_g) of the gas at each step is greater than that at its preceding step by about 1 or 2 cms. [or the volume V_g of the gas at each step is greater than that at its preceding step by about 1 or 2 c c.]. The difference of mercury levels (h cms.) in AB and CD is noted at each step, from which the gas pressure $P_g = (H - h)$

is found out. In all these cases, the product $(P_g.l_g)$ [or $P_g.V_g$] was found to be the same as $H.l$ (or $H.V$). The verifies Boyle's law for pressures less than one atmosphere.

Experimental data :

(A) *Record of Barometric height* (H) :—

TABLE I

Smallest division of the main scale = ···cms.
···v.d. = ···s.d. ; ∴ 1 v.d. = ···s.d.
∴ v.c. = 1 s.d. − 1 v.d. = ··· s.d. = ···cm.

Time of record	Barometric height			
	Scale reading in cm. (S)	Vernier reading in cm. (V) $=(v.r.)\times(v.c.)$	Total reading in cm. $(S+V)$	Mean height in cm. (H)
Before Expt.	...	(...)×(...) = ...	...	...
After Expt.	...	(...)×(...) = ...	...	

(B) *(Pressure-volume) record :*

TABLE II A (when the closed limb *is not graduated*).
Room temperature (at the beginning of Expt.) = ···°C.
.. ,, ,, ,, end ,, ,, = ···°C.

Observations at pressures	No. of obs.	Scale reading at the top of closed tube in cm. (A)	Readings for mercury levels in cm. of,		Difference of mercury levels in cms. $h=(B\sim C)$	Gas pressure $=P_g=(H\pm h)$ cms. of mercury.	Length of gas in cms. $=l_g=(A\sim B)$	$P_g\times l_g$
			closed limb (B)	open limb (C)				
one atmosphere	1.	73·4	50·8	50·8	0	75·9	22·6	...
Above one atmosphere	2.	,,	52·4	58·2	5·8	$(H+h)$ 81·7	21	...
	3.	,,	...	...	...	...	19	...
	4.	,,	...	...	...	...	...	...
	5.	,,	...	...	...	...	...	...
Below one atmosphere	6.	,,	49·4	45	4·4	$(H-h)$ 71·5	24	...
	7.	,,	...	...	...	...	...	...
	8.	,,	...	...	...	...	...	...
	9.	,,	...	...	...	...	...	..

TABLE II B (when the closed limb is *graduated in* c.c.)

Room temperature (at the beginning of Expt.) = ··· °C.

" " " " end " " = ··· °C.

Observations at pressure	No. of obs.	Readings for mercury levels in cm. of,		Difference of mercury levels in cms. $h=(A\sim B)$	Gas pressure $=P_g=(H\pm h)$ cms. of mercury	Volume of the gas in c.c. (V_g)	$(P_g\times V_g)$
		closed limb (A)	open limb (B)				
One atmosphere	1.	45·4	45·4	0	75·9	23·8	...
Above one atmosphere					$(H+h)$		
	2.	47·6	53·8	6·2	82·1	22	...
	3.	...	...	....	....	20	...
	4.	...	...	...	...	...	...
	5.	...	...	...	...	...	...
Below one atmosphere					$(H-h)$		
	6.	43·2	36·8	6·4	69·5	26	...
	7.	...	...	...	...	28	...
	8.	...	...	...	...	...	...
	9.	...	...	...	...	...	...

(C) *Drawing of (P − V) curve* :—

A graph connecting pressure and volume of a given mass of a gas at constant temperature is drawn from the following sample data and is shown in Fig. 20.

Pressure in cms. of mercury→	96·9	89	81	75	70	66	62·2
Volume in c.c.→	7·9	8·6	9·5	10·2	10·9	11·6	12·3

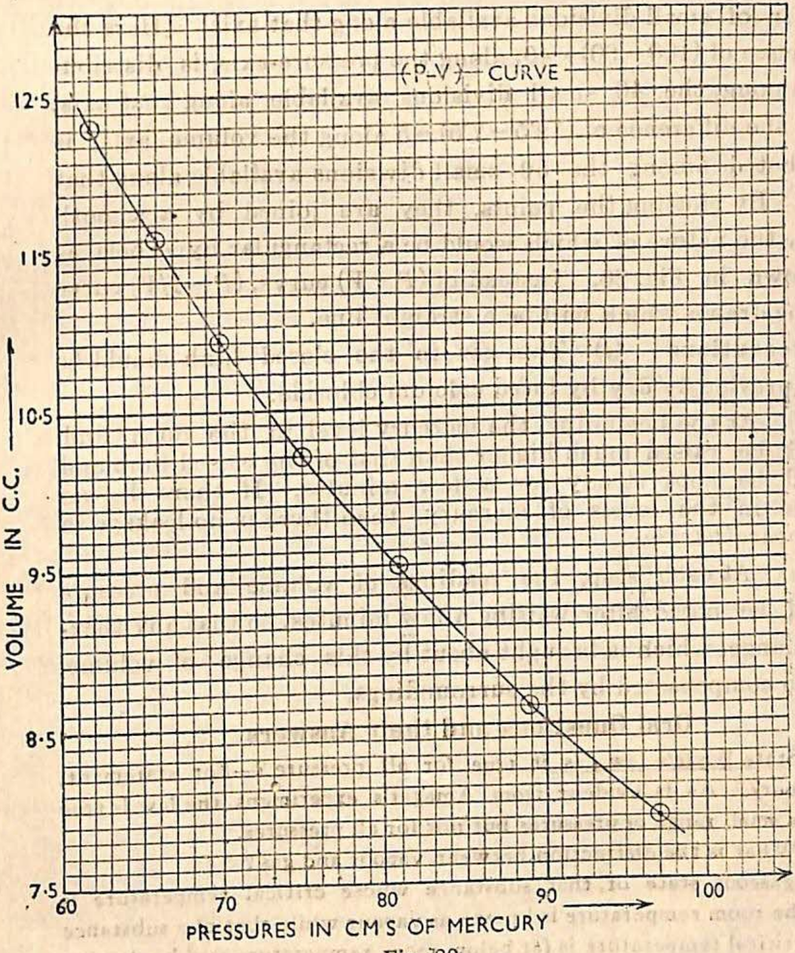

Fig. 20

Pressure in cms. of mercury is plotted along x-axis while the corresponding volume (or length) of the gas is plotted along y-axis. The origins for pressure and volume axes (60,7·5) should be, as far as possible, round numbers which are even lower than the lowest values of pressure (62·2) and volume (7·9) in the given data. Then round numbers (100, 12·5) higher than the highest values of pressure (96·9) and volume (12·3) are to be selected from the given data. The difference between the highest value and the lowest value at the origin along an axis should be equally distributed amongst the number of small divisions available along that axis. [Here the difference of $(100-60)=40$, along the pressure-axis, is distributed among the 40 small divisions available along that axis, while the difference of $(12{\cdot}5-7{\cdot}5)=5$ along the volume axis, is distributed among the 50 small divisions available along that axis.] By plotting the points, they are joined by a smooth curve, the nature of which would be a rectangular hyperbola as is shown in Fig. 20. Instead of $(P-V)$ curve, $(P-1/V)$ curve may be drawn which will be a straight line.

Precautions : (*i*) The gas in the closed limb should be made previously dry by fused calcium chloride.

(*ii*) At the beginning, the mercury level in the open limb should be raised much higher than that of the closed limb and should be kept steady for a few minutes. If there be no change in the levels of mercury, then there is no leakage in the apparatus.

(*iii*) At each step, the readings of volume and pressure should be noted after waiting a few minutes, so that any thermal change, which is brought about by this change of volume, may be compensated by the surroundings.

Oral Questions and their Answers

1. State Boyle's law ; is it true for all pressure ?—For statement, see Theory. As is evident from Amagat's experiment the law is true within a small range of pressures but not for all pressures.

2. What is the distinction between vapour and gas ?

The gaseous state of that substance whose critical temperature is above the room temperature is known as vapour while that of a substance whose critical temperature is far below room temperature will be known as gas. Critical temperature is that temperature above which a gas can never be the liquified by pressure alone.

3. If during experiment the temperature changes or some amount of gas escapes due to leakage, then will the values of PV remain constant throughout ?

No ; for PV will remain constant so long as the temperature of the gas and its mass remain constant.

4. What is a perfect or ideal gas ?—The gas which obeys Boyle's law is known as the perfect or ideal gas.

5. What is the harm if the gas employed is moist ?—As water vapour does not obey Boyle's law, presence of water vapour in the gas will not make (PV) constant.

6. If the temperature of a gas vary then what relation is obeyed by the gas ?

The relation $PV/T=R$, is obeyed by the gas, where the temperature T is in the absolute scale. The constant R is called gas constant. If one gm. molecule of a gas is taken then R is constant for all gases.

7. At each step, why do you wait for sometime before recording the pressure and volume ? [*See* Precaution (*iii*)].

8. What is the cause of the pressure of a gas ?—The gas molecules are moving at random within a closed space and when they collide with the wall of the vessel, the wall experiences a pressure.

9. What is the idea about absolute zero ?—Absolute zero is that temperature (which is—273°C) at which the gas molecules are motionless.

10. What is the nature of $(P-V)$ curve ;—Rectangular hyperbola.

22. Verification of the laws of limiting friction by using an inclined plane.

Apparatus : (*i*) Inclined plane, (*ii*) weight box, (*iii*) metre scale, (*iv*) wooden block with unequal top and bottom faces.

Description of inclined plane : The section of an inclined plane is shown in the figure 21. In this figure, *AB* represents the section of the inclined plane whose lower edge *B* is hinged to one edge of the rectangular horizontal base *BC*. The upper edge *A* of the inclined plane can be raised or lowered along a vertical stand *AC* which is also graduated in cms. If necessary, the upper edge *A* of the inclined plane can be clamped at any point of the vertical scale *AC*. From this vertical scale, the height of the end *A* of the inclined plane from the base *BC* can be obtained. The length of the base *BC* can be measured by a metre scale.

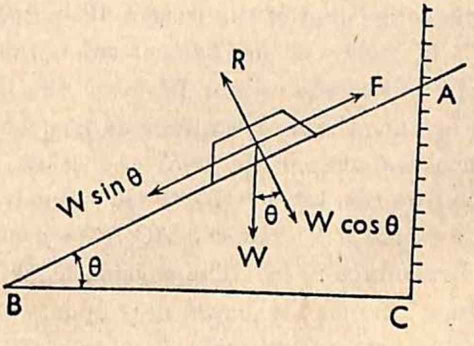

Fig. 21

Theory : When one body moves or tends to move on a rough surface, a force is always called into play along the common tangent to the two surfaces in contact, which resists or tends to resist any relative motion between the two surfaces. This resisting force is called the **force of friction.** But when the body is just on the point of moving or sliding on a rough surface, the force of friction then called into play is maximum and is known as the **limiting friction.** The limiting friction satisfies the following two laws :—

Law I.—The magnitude of the limiting friction (F) always bears a constant ratio (μ) to the normal reaction (R) between the two bodies in contact. Normal reaction (R) is equal to the pressure which the plane exerts on the body in the upward direction along the common normal to the surfaces in contact. Thus $F/R=\mu$ (constant). This constant is known as the **co-efficient of friction.**

Law II.—The co-efficient of friction between the two bodies depends on the nature of roughness of the materials of which the bodies are composed, but not on the shape or extent of the surfaces in contact.

To verify the laws, a body of weight W should be put on a rough inclined plane whose inclination with the horizontal is θ (Fig. 21). If the body is just on the point of sliding down the plane, component of the weight W perpendicular to the plane *viz.*, $W\cos\theta$ will just balance the normal reaction R, while the component of the weight W down the plane, *viz.*, $W\sin\theta$ will just balance the force of limiting friction (F) acting up the plane. Hence we get, $W\sin\theta=F$ and $W\cos\theta=R$. By taking the ratio, we get, $\tan\theta=(F/R)=\mu$. But from Fig. 21 we see that, $\tan\theta=(AC/BC)$. Hence, $(AC/BC)=\mu=\text{constant}$.

Procedure : (*i*) The wooden block with a suitable load on it (say 100 gms.) is placed near about the middle of the inclined plane and the inclination θ of the plane with the horizontal is *gradually and slowly* increased until the block *just begins* to slide down the plane. At this time, the height AC of the upper end of the plane from the base BC is noted from the scale on AC. This procedure is repeated thrice and the mean value of AC is found out.

(*ii*) The length BC of the base is measured by a metre scale and the ratio of AC and BC, i.e. AC/BC is found out.

(*iii*) Five more different weights from the weight box, are now successively put on the block and the operation (*i*) is repeated. In each case, we shall see, that the ratio of the height of the plane to its base, *viz.*, AC/BC is remaining constant, which verifies the first law of limiting friction.

(*iv*) To verify the second law, the block is put on the inclined plane with its upside down so that the extent of the surfaces in contact may be different. This time also, the entire operations from (*i*) to (*iii*) are repeated and in all these observations also, we shall see that the ratio of the height of the plane to its base, *viz.*, AC/BC is remaining the same as in the previous set of operations. This verifies the second law of limiting friction.

Experimental data :

Block-surface in contact with the plane.	No. of obs.	Loads on the block in gms.	Height of the plane in cm. (AC)	Mean AC in cm.	Length of the base in cm. (BC)	Ratio = $\mu = \frac{AC}{BC}$	Remark	Mean μ
Bigger face in contact	1.	100	... ...	...	...	...	First law is verified	...
	2.	120	... ...	....	....	....		
	etc.	etc.	etc.	etc.	etc.	etc.		
	6.	200	... ...	...	...	...		
Smaller face in contact	1.	100	... ...	...	...	...	Second law is verified	
	2.	120	... ...	...	...	...		
	etc.	etc.	etc.	etc.	etc.	etc.		
	6.	200	... ...	...	...	...		

Precautions : (*i*) The degree of roughness of the inclined plane cannot be expected to be the same at all places and hence block should be placed at the *same place* in each observation.

(*ii*) The block should be placed on the inclined plane in such a way that the fibres of the block and that of the plane may be parallel ; otherwise friction would be different.

(*iii*) The surfaces in contact must be *dry* ; otherwise frictional force would be different.

(*iv*) The plane should be raised *very slowly* to find the actual inclination of the plane at which the *motion of the block just ensues*.

Oral Questions and their Answers

1. Define (*a*) friction, (*b*) limiting friction, (*c*) coefficient of friction, (*d*) angle of friction.

For (*a*), (*b*) and (*c*)—*See* Theory. (*d*) Angle of friction is the angle which the resultant of the force of limiting friction and normal reaction makes with the normal reaction.

2. Distinguish between (*a*) static and dynamic friction (*b*) sliding and rolling friction.

(*a*) (*i*) When a body rests in contact with a rough surface and is acted on by external forces urging the body to move on the surface, the force of friction, which is called into play at the point of contact, before their relative motion ensues, is called static friction which can attain a maximum value known as the limiting friction. (*ii*) But when the relative motion between the bodies begins, the force of friction then exerted is called dynamic friction whose value is slightly less than that of limiting friction.

(*b*) (*i*) A rough surface always contains minute ups and downs. Sliding friction is due to the inter-locking of these irregularities of the two surfaces in contact. (*ii*) When one body rolls on a surface, the supporting surface is depressed a little creating a ridge in front of the rolling body. Rolling friction is due to the constant climbing of the rolling body over these minute ridges of the surface. The coefficient of rolling friction is much smaller than that of sliding friction.

3. How the friction between two moving surfaces is reduced ?

If non-corrosive liquids or solid particles (such as particles of graphite) are introduced between the surfaces, the friction becomes minimum. The liquids keep the surfaces separate, while the solid particles act as rollers between the moving surfaces by which friction is reduced.

4. What are the advantages and disadvantages of the existence of friction ?

Walking on roads, stopping of train, driving of machinery by belts are all possible due to friction. The moving parts of a machine generates much heat by friction, as a result energy is unnecessarily wasted. To reduce this wastage of energy lubricants are employed.

23. Determination of the coefficient of viscosity of a liquid by its flow through a capillary tube.

Apparatus : *First arrangement* :—The apparatus employed to determine the coefficient of viscosity of a liquid is shown in Fig. 22. It consists of a constant-level tank N in which there is the inflow pipe I and outflow pipe O. A capillary tube C of about 40 to 50 cms. long is attached to a glass tube G by a rubber tube K. The capillary tube C is almost of uniform bore and is kept *slightly inclined* to the horizontal. The tube G ends above the rubber cork R which closes the bottom of the tank N. The supply of liquid through I is slightly in excess of that flowing out through the capillary tube C and this excess liquid flows out through the tube O. The height of the free surface of the liquid in the tank N above the outflow end E of the tube C can be measured by a cathetometer.

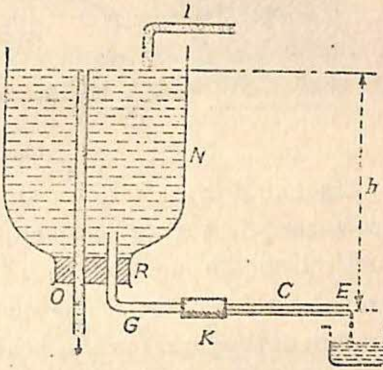

Fig. 22

Second arrangement :—Another arrangement shown in Fig. 22(a) may be conveniently employed in the laboratory to find the coefficient of viscosity (η) of a liquid. V is a glass vessel which contains the experimental liquid. The mouth of the vessel is closed by a rubber cork R, through which passes a glass tube TO, open at both ends. The lower end O remains well below the surface of the liquid in V. As the liquid flows out of the vessel V, air bubbles from the atmosphere enters the vessel V through the tube T, by which the end O of it always remains at atmospheric pressure, so long at the liquid level in V remains above O.

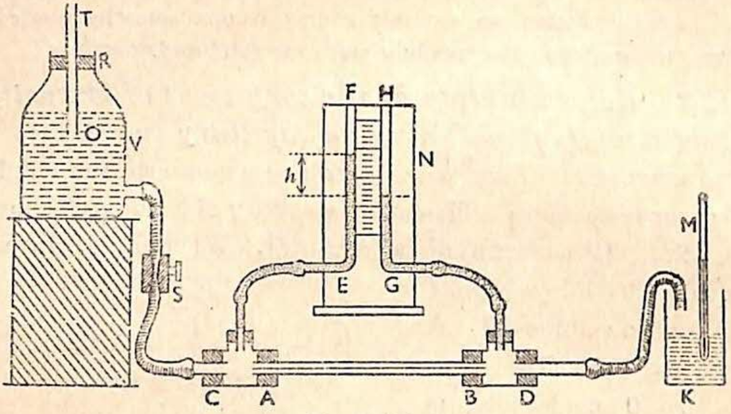

Fig. 22*(a)*

The liquid from V flows to the junction at C through a screw cap S, thence through the capillary tube AB of known length (l) to the junction at D and thence to the beaker K through a rubber tube. The thermometer M measures the temperature of the liquid in the beaker K. The screw cap S should be so adjusted that the liquid may issue out in a very slow stream or in succession of drops. If the height of liquid in the arm GH of the manometer N is not appreciable then a second screw cap is to be applied in the rubber tube from D which goes to the beaker K. The difference of liquid levels (h) in the two arms (EF and GH) of the manometer (N) can be measured by a cathetometer. When everything is steady, the liquid should be collected in the beaker K.

Theory : When the pressure difference $P(=h\rho g)$, under which the liquid flows through a capillary tube, is not very large, *i.e.* the motion of the liquid is in streamlines, the volume (V) of the liquid that flows out in *one second* through a capillary tube of radius r (radius of the bore of the tube) and length l is given by

$$V=\frac{\pi P r^4}{8\eta l}.$$

Here η is the coefficient of viscosity of the liquid,

$$\text{or} \qquad \eta = \frac{\pi P r^4}{8\,Vl}. \qquad \ldots \qquad \ldots \qquad \ldots \quad (1)$$

The relation (1) may be employed to find the coefficient of viscosity (η) of liquid.

Procedure : (*i*) The length l of the capillary tube (which is about 40 cms. long and 1 mm. in internal diameter) is measured thrice by a scale and its mean value (l) is found out.

(*ii*) The bore of the capillary tube is first washed with dil. caustic soda, then with dil. nitric acid and finally in a stream of cold water. The tube is then made dry by passing hot air in it and a column of mercury covering almost the entire length of the tube is sucked in it. The length (L) of this mercury column is measured thrice by a scale and its mean value (L) is found out. This mercury is then weighed in a crucible whose mass is already known. From this, the mass m of mercury is obtained [Table I]. The value of r^2 and hence r^4 is determined from the relation,

$$m = \pi r^2\, L \times 13{\cdot}6. \quad \text{[Table I]} \qquad \ldots \quad (2)$$

(*iii*) A cathetometer, kept at a distance, is adjusted in such a way that its pillar is vertical and the axis of the telescope is horizontal at its every position. The cross-wire of the telescope is then focussed by avoiding parallax. The telescope is then focussed successively on the surface of the liquid in the tank N and the axis of the outflow end E of the capillary tube C. [or the telescope is successively focussed on the surfaces of liquid in the two arms EF and GH of the manometer N,—Fig. 22(*a*)]. The readings R_1 and R_2 of the vernier and scale are noted in each case and the difference of these two readings ($R_1 - R_2$) gives the value of h.

(*iv*) The temperature of the liquid ($T^\circ C$) in the tank is noted by a thermometer and the density (ρ) of the liquid at this temperature is either determined by a sp. gr. bottle or found out from a table. Then the value of $P = h\rho g$ is found out.

(*v*) The mass (M_1) of an empty beaker is first determined by a balance and then the outflowing liquid is collected in it for a known interval of time t (determined by a stop-clock) until the beaker is half-full. The mass (M_1+M) of the beaker with the liquid in it is found out and the mass of the liquid collected in t seconds is thus given by M. Hence the volume (V) of the liquid collected in one sec. is $V=M/\rho t$.

(vi) The experiment is repeated for different heights of liquid, taking care that the motion of the liquid always remains in stream lines. If desired the experiment may be repeated with another capillary tube.

(iii) A graph is then to be drawn with h along the x-axis and the corresponding value of V (volume of liquid flowing out per second) along the y-axis. This graph will indicate the variation of V with h.

Experimental data :

(A) *Measurement of length (l) of capillary tube :—*

$$l=\frac{\cdots+\cdots+\cdots}{3}= \quad \cdots \quad \text{cm.}$$

(B) *Measurement of radius (r) of capillary tube :—*

TABLE I

Length of Hg column in cm. (L)	Mean L in cm.	Mass of empty crucible (m_1) in gms.	Mass of crucible + Hg (m_1+m) in gms.	$r^2=m/(\pi L\times 13\cdot 6)$	r^4
		.. + ...			
(i) ...		+ ... + ...			
(ii) ...	...	= ...gm.	...	...	...
(iii) ...					

(C) *Cathetometer readings to find P $(=h\rho g)$:—*

Value of 1 small division of main scale = ... cm.

Total number of vernier divisions $(v.d.)$ = ...

... $v.d.$ = ... $s.d.$

∴ 1 $v.d.$ = ... $s.d.$

Vernier constant $(v.c.)=(1\ s.d.-1\ v.d.)=$ ... cm.

TABLE II

No. of Obs.	Reading of liq. level in the tank or in the arm EF of manometer in cm. (R_1)			Reading of the axis of tube C at E or of liq. level in the arm GH of manometer in cm. (R_2)			Difference in cm. $h=(R_1 \sim R_2)$	Temp. of liq. in the tank (T)°C	Density of liq. at T°C $=\rho$ gms./c.c.	Press. diff. $=P=h\rho g$ dynes/sq. cm.
	Scale (S)	Vernier (V) $=(v.r)\times(v.c)$	Total $R_1=$ $(S+V)$	Scale (S)	Vernier (V) $=(v.r)\times(v.c)$	Total $R_2=$ $(S+V)$				
1	...	(...)×(...)	...	...	(...)×(...)	...	...	...	...	...
2	....	(...)×(....)	...	...	(....)×(...)	...	...	...	...	....
etc.	etc.	etc.	etc.	etc,	etc.	etc.	etc.	etc,	etc.	etc.
5	...	(....)×(...)	...	...	(...)×(...)	...	....	...	...	...

(D) *To find volume* (V) *of liquid collected in one second* :—

TABLE III

No. of Obs.	Mass of empty beaker (M_1)	Mass of beaker + liquid collected in t secs. (M_1+M)	Mass of liquid in gms. collected in t secs. (M)	Time of collection of liquid in secs. (t)	Volume of liquid collected in one sec. is $V=\frac{M}{\rho t}$ c.c.
1	...gm. + ... gm. +...mg. + ...mg. + ... = ...gm.	.. gm. + .. gm. + ...mg. + .. mg. + ... = .. gm.	...	...min....secs. = .. secs.	...
2	...	...	...	...	...
etc.	...	...	...	...	...
5	...	...	...	...	...

(E) *To find* η :—

TABLE IV

No. of Obs.	h in cm.	density ρ of liq. at temp. T°C in gms./c.c.	l in cm.	V in c.c.	r^4	η at T°C in c.g.s. unit	Mean η at T°C in c.g.s. unit
1	...	...	....	....	...	...	
2	...	,,	,,	....	,,	...	
etc.	etc.	,,	,,	etc.	,,	etc.	...
5	...	,,	,,	...	,,	...	

Calculations :

$$\eta = \frac{\pi P r^4}{8Vl} = \frac{\pi h \rho g r^4}{8Vl} = \quad \cdots \qquad \text{gms. cm.}^{-1}\ \text{sec.}^{-1}\ \text{at}\ T°C.$$

Precautions : *i*) Since radius r occurs in the fourth power, the bore of the capillary tube should be as uniform as possible and this can be previously tested by introducing a short column of mercury in the tube and measuring its length at various parts.

(*ii*) Owing to capillarity the outflowing liquid from the end E of the tube C may run back along the outside of the tube. To prevent this, either the tube should be kept slightly inclined to the horizontal or a little vaseline should be smeared on the outside of the tube near its free end, when the capillary tube is kept horizontal. [for first arrangement].

(*iii*) The pressure difference, under which the liquid flows, must not be *high* to make the flow turbulent which will be evident from the straight line curve obtained by plotting V along the y-axis and h along x-axis.

(*iv*) If the error due to kinetic energy of the liquid and its acceleration near the entrance end of the capillary tube is to be eliminated, the following relation is to be employed to find η.

$$\eta = \frac{\pi r^4}{8V(l + 1{\cdot}64r)} \rho g \left(h - \frac{kV^2}{g\pi^2 r^4}\right).$$

The value of k is approximately equal to unity but for accurate work its value should be determined by calibration.

(v) For greater accuracy, the quantity of liquid collected should be appreciable.

(vi) The temperature of the liquid should be noted carefully, for the value of its viscosity changes rapidly with temperature.

Oral Questions and their Answers

1. What do you mean by the term 'viscosity' and 'coefficient of viscosity' of a liquid ?

Whenever there is a relative motion between two layers of a liquid a tangential opposition force is set up between the layers to destroy this relative motion. This property of the liquid is called viscosity and it is analogous to friction. This tangential force per unit area on either of the two liquid surfaces, when there is unit velocity gradient between them, is known as the coefficient of viscosity.

2. What do you mean by streamline motion and turbulent motion ? When the pressure difference, under which the liquid flows in a capillary tube is small, the particles of the liquid move in straight paths and this kind of motion of liquid is known as streamline motion. When the pressure difference is made large, the particles flow in zigzag paths and this motion is called turbulent motion.

3. How does the coffiecient of viscosity change with temperature ?

In the case of liquids viscosity diminishes with temperature, while in the case of gases it increases with temperature.

4. Discuss the nature of flow of liquid in a capillary tube.

When streamline motion occurs, the layer of liquid in contact with the capillary tube is at rest while the velocity of the other layers increases as we go towards the axis of the tube at which the velocity is maximum.

5. Which quantity would you measure with great care ?

As the radius of tube occurs in the fourth power, it should be measured with great accuracy and proper care should be taken to select a tube of uniform bore. (See precautions).

6. What is the harm if the capillary tube is not horizontal ?

If the tube is horizontal, then the height h of the liquid is to be measured from the liquid level in the tank to the axis of the capillary tube. When the capillary tube is inclined, the height h of the liquid is to be measured from the liquid level in the tank to the free end E of the capillary tube C.

7. What is the unit of the coefficient of viscosity ? [See 'Calculation']

24. Determination of surface tension of a liquid by the capillary tube method and to verify Jurin's law.

Theory : If a capillary glass tube of *almost uniform circular bore* is partly introduced in a liquid which wets glass and is kept *vertical*, the liquid rises in the tube. If h be the height of the base of the concave mensicus in the tube from the outer level of the liquid and if r be the internal radius of the tube at which the meniscus stands then the surface tension T of the liquid is given by

$$T=\frac{\rho g r}{2}(h+\tfrac{1}{3}r), \qquad \ldots \qquad \ldots \quad (1)$$

where ρ is the density of the liquid and g is the acceleration due to gravity.

Procedure : (*i*) A long glass tube of almost uniform bore of about $\frac{1}{2}$ a centimetre in diameter is selected and its bore is cleaned. From this tube, five or six capillary tubes of different diameters are drawn. The bores of the capillary tubes should be as uniform as possible.*

(*ii*) These capillary tubes are fixed parallel to each other on a strip of glass plate by soft wax. [To fix the tubes parallel to each other, a graph paper is placed below the glass strip and each tube is fixed on the glass strip, coinciding with a line on the paper. The distance of separation between two neighbouring tubes may be equal to two small divisions of the graph paper.] A clean needle with pointed ends is also fixed to the glass strip parallel to the tubes but not close to them, in order that the capillary action between the needle and its adjacent tube may not arise. The glass strip is kept clamped by a stand, so that the tubes are all vertical.

---

*The selected glass tube is first cut into several pieces so that each piece is about eight inches long. The inside of these pieces is first cleaned by moving a clean cotton pad several times by a thin rod. Next the pieces are washed with dilute nitric acid, and then with dilute caustic soda solution and finally in a stream of tap water (not distilled water). They should be dried in alcohol and ether.

Each piece is then to be heated at the middle by a fish-tail burner by keeping it in a slow and continuous rotation. When the heated portion becomes red hot and soft the two ends are pulled out to get a capillary tube at the middle. The bore of the capillary tube formed at the middle will be wide or narrow according as the pull is slow or quick. In this way, six or seven capillary tubes of almost uniform circular bores but of different diameters are cut off from the drawn portions.

(*iii*) A clean glass beaker is filled almost completely with the given liquid and its temperature $\theta_1 {}^\circ C$ is noted.

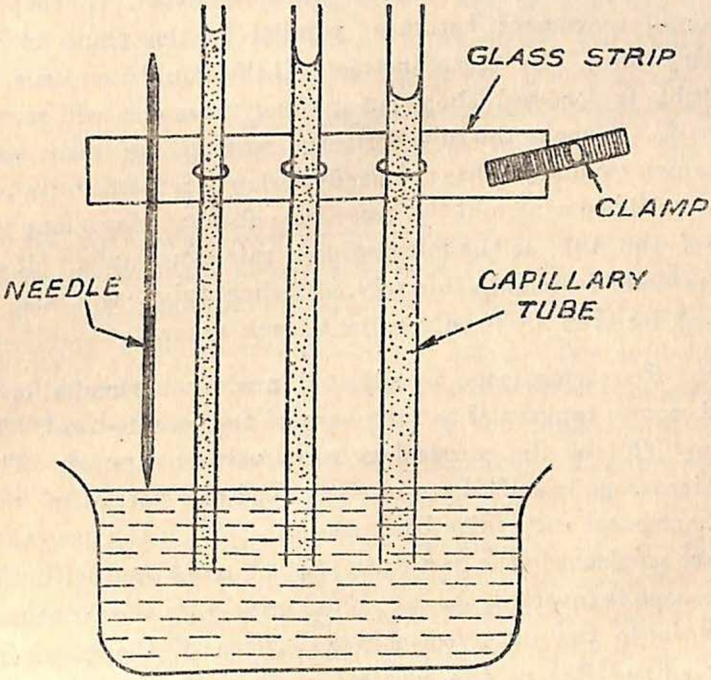

Fig. 23

The position of the stand is arranged, so that the tubes remain vertical with their lower ends immersed in the liquid, while the lower end of the needle just touches the liquid surface. The arrangement is shown in Fig. 23. At first, the tubes should be dipped deeper in the liquid and then should be raised, until the lower end of the needle just touches the liquid surface.

By this, the inside of the tubes above the meniscus will be well-wetted.

(*iv*) With the help of a spirit level, the base of the travelling microscope is made horizontal with the levelling screws attached to the base. The axis of the microscope tube is also made horizontal by putting the spirit level on it and by adjusting its inclination. The cross-wire of the microscope is sharply focussed.

(*v*) The base of the microscope is adjusted, so that its horizontal movement becomes parallel to the plane of the capillary tubes. By this adjustment, if the liquid meniscus, in one tube is focussed, then that in other tubes also will remain focussed. To make the tube perfectly vertical, the glass strip (on which capillary tubes are fixed) is slowly rotated in its own plane, until the centre of the cross-wire always goes along the axis of the tube as the microscope is raised upwards. (If one tube is made vertical in this way, all other tubes will also be vertical, for they are fixed parallel to each other.

(*vi*) The microscope is adjusted until its horizontal cross-wire becomes tangential to the image of the needle-head. The reading (R_1) of the vertical scale and vernier is noted. Then the microscope is shifted horizontally (and also vertically) until the horizontal cross-wire becomes tangential to the base of the concave meniscus in the first tube. [As the image seen within the microscope is inverted, the horizontal cross-wire should be made tangential to the observed convex surface of the meniscus.] The reading (R_2) of the vertical scale and vernier is noted. In this way the readings corresponding to the base of the concave meniscus of second, third, etc. tubes are noted. Then the difference (x) between the readings of the needle-head (R_1) and the base of the concave meniscus (R_2) in each tube is found out. *i.e.* we find $x=R_1 \sim R_2$. If l be the length of the needle, the height of the meniscus from the level of liquid in the beaker, is given by $h=l \pm x$. [The + or − sign should be taken according as the needle-head is *below* or *above* the meniscus.]

The temperature θ_2°C of the liquid is again noted and the mean temperature $\theta=(\theta_1+\theta_2)/2$ of the given liquid during the experiment is found out.

(*vii*) The position of the meniscus at each tube is marked by an ink dot on the outer surface of the tube. Each tube is cut at the ink dot by a sharp file or better by a fine-grained sand paper. These tubes are then fixed parallel to each other on the strip of glass, by a soft wax so that the cut ends of all the tubes are in one straight line. The glass strip is kept clamped with its surface horizontal, so that all the tubes are in the horizontal plane and the cut ends of all the tubes are directed towards the microscope (whose axis is horizontal). The base of the microscope is adjusted, so that its horizontal line of traverse becomes parallel to the straight line joining the cut ends of the tube.

(*viii*) The microscope is then focussed on the cut end of the first tube and the vertical cross-wire is made tangential to the left side of the inner bore which is almost circular and the reading (R_3) of the horizontal scale is noted. The microscope is then moved horizontally until the same vertical cross-wire becomes tangential to the right side of the inner bore. The reading R_4 of the horizontal scale is noted. The horizontal diameter $D_1(=R_3\sim R_4)$ of the bore is thus found out.

Then in the same manner, the readings R_5 and R_6 of the vertical scale are noted, when the horizontal cross-wire becomes tangential to the lower end and upper end of the inner bore of the capillary tube. The vertical diameter is then given by $D_2=(R_5\sim R_6)$. The mean diameter $D=(D_1+D_2)/2$ of the first tube is thus determined, from which the radius $r\ (=D/2)$ is found out.

Proceeding in this way, the mean radii of other tubes are determined.

(*ix*) The length l of the needle is measured by putting it horizontally on the base of the microscope and taking the difference of the two readings obtained from the horizontal scale, when the vertical tube of the microscope is focussed on the two ends of the needle successively.

(x) The sp. gravity (ρ) of the given liquid is determined by employing a sp. gravity bottle.

Experimental data :

(A) *Constants of microscope and determination of h :—*

1 smallest division of the scale = ... cm.

... $v.d.$ = ... $s.d.$

$\therefore$ 1 $v.d.$ = ... $s.d.$

$v.c. = 1\ s.d. - 1\ v.d.$ = ... $s.d.$ = ... cm.

Initial temperature of the liquid $= \theta_1 {}^\circ C$ = ... °C

Final ,, ,, ,, ,, $= \theta_2 {}^\circ C$ = ... °C

Mean temperature of liquid during experiment $= \theta^\circ C = (\theta_1 + \theta_2)/2$ = ... °C.

TABLE I

Tube no.	Readings in cm. of						Difference in cm. = $x = (R_1 \sim R_2)$	Height in cm. of the meniscus $= h = l \pm x$
	needle-head			meniscus-base				
	Scale (S)	Vernier (V)	Total $= R_1 = (S+V)$	Scale (S)	Vernier (V)	Total $= R_2 = (S+V)$		
1.								
2.								
etc.								
7.								

(B) *Measurement of radius* (r) *of the tubes* :—

TABLE II

Tube no.	Direction of obs.	Readings in cm. for the						Diameter in cm.	Mean diameter in cm. $D=\frac{D_1+D_2}{2}$	Mean radius in cm. $r=\frac{D}{2}$
		left or lower end of the bore from,			right or upper end of the bore from,					
		Scale (S)	Vernier (V)	Total = ($S+V$)	Scale (S)	Vernier (V)	Total = ($S+V$)			
1.	horizontal	....	...	.. $=R_3$	...	...	.. $=R_4$	$D_1=R_3 \sim R_4$ $=$	...	...
	vertical	...	...	.. $=R_5$	...	...	.. $=R_6$	$D_2=R_5 \sim R_6$ $=$		
2.	horizontal	....	...	.. $=R_3$	...	...	.. $=R_4$	$D_1=R_3 \sim R_4$ $=$ ..	...	...
	vertical	...	...	.. $=R_5$	...	...	.. $=R_6$	$D_6=R_5 \sim R_6$ $=$ ..		
etc.	horzontal									
	vertical									

(C) *Measurement of the length* (l) *of the needle* :—

TABLE III

Readings in cm. for the						Length in cm. $=l=$ ($R' \sim R''$)
End I			End II			
Scale (S)	Vernier (V)	Total $=R'$ ($S+V$)	Scale (S)	Vernier (V)	Total $=R''$ $=(S+V)$	
...	...	...	...	...	...	...

(D) *Determination of the density* (ρ) *of liquid* :—

Temperature of water employed = $t°C$ = ... °C

Density of water at $t°C = \rho_t$ = ... gms./c.c.

TABLE IV

Mass of empty bottle $= W_1$ gms.	Mass of bottle + liquid $= W_2$ gms.	Mass of bottle + water at $t°C$ $= W_3$ gms.	Density of liq. $= \rho = \frac{W_2 - W_1}{W_3 - W_1}\rho_t$ gms/c.c.

(E) *Calculation of T* :—

TABLE V

Tube no.	Effective height in cm. $h' = h + \frac{1}{3}r$	Radius in cm. r	$h'r$	Mean $h'r$	Surface tension is $T = \frac{h'\rho g r}{2}$ dynes per cm.
1.					
2.					... (from mean $h'r$).
etc.					... (from graph).
7.					

(F) *Verification of Jurin's law* :—

According to Jurin's law $h'r$ should remain constant. Almost constant value of $h'r$ as shown in the fourth column of the Table V verifies the law. A graph is to be drawn with r as abscissa and the corresponding value of h' as ordinate. The graph would be found to be a rectangular hyperbola which also verifies the law.

Calculation of T : The mean value of $h'r$, as obtained in column five of Table V as also the values of h' and r from a point on the graph should be employed to calculate surface tension. Thus the surface tension of the liquid at its mean temperature $\theta°C$ is given by,

$$T=\frac{h'r\rho g}{2} \quad \ldots \quad = \quad \ldots \text{ dynes/cm.}$$

Precautions : (*i*) The surface tension depends on the radius of the tube at which the liquid meniscus stands. As it is difficult to cut the tube exactly at the position of the meniscus, the tube should be of as uniform bore as possible.

(*ii*) The tubes should be made perfectly vertical. This should be done in the manner as described in the procedure.

(*iii*) As surface tension depends on temperature, the temperature of the liquid should be noted before and after the experiment. The surface tension thus determined will correspond to this mean temperature.

(*iv*) As surface tension is lowered by the presence of a small amount of grease, the vessel and tubes must be clean and the lower part of the tubes should not be contaminated by hand during the fixing of the tubes to the strip of the glass. Tap water and *not distilled water* should be employed in washing.

(*v*) All tubes must be fixed parallel to each other and for this purpose a graph paper should be placed below the glass strip and each tube should be fixed coinciding with a line of the paper.

(*vi*) The horizontal line of movement of the microscope should be parallel to the plane of the tubes.

Oral Questions and their Answers

1. Define (*a*) surface tension, (*b*) angle of contact, (*c*) cohesive and adhesive forces.

(*a*) If a straight line of unit length is drawn on the liquid surface, the portions of the surface on opposite sides of the line tend to draw away from each other with a force which is perpendicular to the line and tangential to the liquid surface. This force is called surface tension and its unit in c.g.s. system is dynes per cm.

(*b*) The angle of contact between a glass plate and the liquid is the angle, which the tangent to the liquid surface at the point of contact makes with the immersed surface of glass. It is acute for liquids which wet glass (such as water) but obtuse for liquids which do not wet glass (such as mercury).

(c) Cohesive force is the force of attraction between two similar kinds of molecules, while adhesive force is the force of attraction between two dissimilar kinds of molecules.

2. Will all liquids rise in the capillary glass tubes ?

No. The liquids, which wet glass and whose angle of contact is acute. will rise in the tube and its free surface in the tube will be concave upwards. The liquids, which do not wet glass, will be depressed in the tube and its free surface in the tube will be convex upwards.

3. What is the effect of temperature and electrification on the surface tension of a liquid ?

Surface tension decreases with the rise of temperature of the liquid and the state of electrification of the surface. Surface tension disappears at critical temperature.

4. Does the medium in contact with the liquid surface influence the value of surface tension ?

Yes ; the value of surface tension of water in contact with air is nearly 74, while that in contact with its own vapour is 71·4, nearly. The value of surface tension of water is much lowered in contact with oil.

5. Can you name some phenomena on surface tension ?

Spreading of oil on water, calming of waves by oil, gyration of camphor on water, floating of thin iron needle on water, formation of dew drops are examples of phenomena based on surface tension.

6. How does the surface tension of pure water differ from that of the solution of a salt in water ?

If n gm.-equivalents of a salt are present in one litre of a solution, the surface tension of the solution (T_n) is related to that of pure water (T) at the same temperature by the relation $T_n = T + An$, where A is a constant which is different for different salts and is nearly 2.

7. Will the height of liquid in the capillary tube be affected by change of the diameter of the tube ?

Yes ; the height will be inversely proportional to the radius of the tube where meniscus stands.

8. Why do you measure the diameter of the tube at the position of meniscus and nowhere else ? —[See Precaution (*i*)].

9. Do you consider the method an accurate one ?—No, for (*i*) the angle of contact, which was assumed to be zero, is not so, (*ii*) the liquid surface cannot be made perfectly clean and (*iii*) it cannot be adopted to measure surface tension at different temperatures.

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CHAPTER III

HEAT

25. *General Precautions to be taken in the experiments on heat.*

(*a*) **In handling thermometers:** (*i*) The bulb of the thermometer should *never be griped* by hand.

(*ii*) It should never be introduced in a bath whose temperature is expected to be *higher than the maximum temperature* for which it is intended.

(*iii*) When the reading of thermometer is to be taken, *parallax* should be avoided, *i.e.*, the line joining the eye and the mercury meniscus must be at right angles to the stem.

(*iv*) When determining the actual temperature of a bath, the *zero-error* of the thermometer should be previously determined.

(*v*) When two or more thermometers are employed to note the rise of temperature (but not the actual temperature), the *mean value of the rise of temperature* shown by different thermometers should be taken to avoid the different zero-errors of different thermometers.

(*vi*) To record the temperature of a substance the bulb of the thermometer should be kept *very close to the hot body* but not in contact with it.

(*vii*) When a substance of appreciable dimension, or a substance confined in a non-conducting enclosure, is to be heated by introducing it in a hot liquid or vapour bath, the temperature of the bath (as indicated by a thermometer kept immersed in the hot liquid or vapour bath) should be maintained constant for an appreciable time (say, five minutes) so that the temperature of every part of the substance may be equal to that of the bath which is really measured.

(*viii*) When a badly conducting substance is to be heated, it should be preferably broken out into *small pieces*, so that the temperature throughout the mass of every piece may be the same.

(*ix*) The thermometer should be introduced in the hot bath in such a way that the length of the mercury column outside the hot bath may be as small as possible.

(*x*) To obtain greater accuracy in the measurement of small changes of temperature, a thermometer, reading $\frac{1}{10}°C$, should be employed (as in the sp. heat experiment).

(*xi*) When noting the temperature of a room, the bulb of the thermometer *must not be moist* and the thermometer should be kept at a place which is far away from the hot or cold body and where there is no current of air.

(b) In heating a chamber or a bath of liquid : (*i*) When a chamber is to be heated by steam, water taken in the boiler for producing steam must *not* be *too small or too large*.

(*ii*) If a moderately long chamber is to be heated by steam, two thermometers are to be employed,—one near the entrance pipe and the other near to the exit pipe of steam. The *mean value of the changes of temperature* shown by the two thermometers should be accepted (as in the case of expansion of a solid, by microscope and optical lever and also in the case of expansion of mercury by Dulong and Petit's apparatus).

(*iii*) When a solid is heated in hot air, as in steam heater, steam should be passed for an appreciable time until the temperature of the hot air is *nearly the same* as that of steam.

(*iv*) When a substance is heated by introducing it in a liquid bath heated from below, the liquid should be *stirred continually* to have a uniform temperature throughout the mass of the liquid.

(*v*) If the vapour of the liquid in the hot bath is inflamable, proper care should be taken *not to bring the flame in direct contact with the vapour* and the vessel containing the liquid should be long enough to keep the vapour at a safe distance from the flame. [As is employed in the determination of the boiling point of benzene by platinum thermometer].

(c) In minimising the transference of heat from or to the body : Transference of heat from or to the body is an important source of error in calorimetric experiment. The methods, which are adopted to minimise such transference of heat are enumerated below.

(*i*) To prevent the transference of heat by conduction and radiation the calorimeter and its contents should be kept separated from the hot sources by a wooden partition. To avoid further transference of heat, the calorimeter is kept suspended inside a copper vessel with the help of three strings attached to the rim of a copper vessel. The copper vessel with the calorimeter suspended in it is kept inside a wooden vessel packed with a non-conducting material such as cotton wool.

(*ii*) To minimise the loss or gain of heat by radiation the *outside of the calorimeter and the inside of the copper vessel should be kept highly polished.*

Again, the rate of loss or gain of heat by radiation will be smaller when the surface area of the calorimeter and the area of the exposed surface of the liquid in the calorimeter is as small as possible. This minimum surface area will be approximately attained when the *height of the calorimater is nearly 1·25 times its diameter.* In spite of the precautions taken above, some loss of heat will always occur by radiation, for which a correction will have to be applied by applying any one of the following methods :—

1. In the compensation method, the calorimeter and its contents should be *cooled (or heated) as much below (or above) the room temperature as the final temperature is above (or below) it.*

2. In the second method, correction for radiation is found out by continually noting the temperature of the calorimetric liquid after an interval of ½ a minute, throughout an interval of time beginning from the introduction of hot solid within the calorimetric liquid up to the moment at which the temperature of the liquid falls below its maximum-attained temperature by about two or three degrees. (For details, see Expt. on the 'determination of sp. heat of a liquid.')

3. In the third method, the fall of temperature of the hot body from its maximum-attained temperature during half of the interval of time required to reach its maximum temperature is noted. When this fall of temperature is added to the maximum temperature, we get approximately a temperature which would have been attained, had there been no radiation at all.

Thus if t be the time required to attain the maximum temperature $\theta^\circ C$ and if $x^\circ C$ be the fall of temperature in time $t/2$ counted from the time t, the correct temperature of the bath is given by

$\theta' = (\theta + x)^\circ C$. [For proof see Expt. on the 'determination of J'].

26. Determination of the mean coefficient of linear expansion of a solid rod between room temperature and steam temperature.

(a) By travelling microscope.

Apparatus : The rod AB, whose coefficient of linear expansion is wanted, is about 1 metre long and is surrounded by a jacket J in which steam can be passed so as to heat the rod. The steam enters the jacket through the pipe P_1 and leaves it through the pipe P_2.

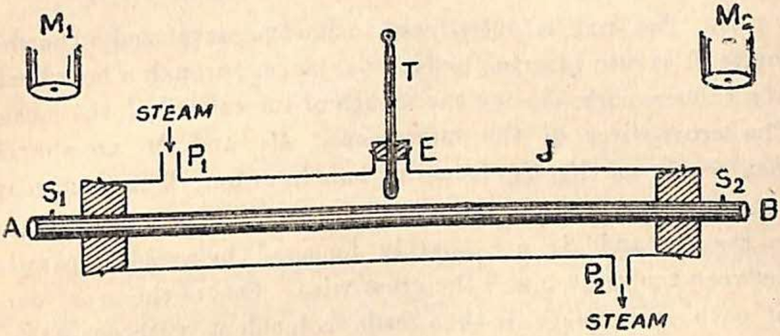

Fig. 24

The thermometer T, whose bulb is introduced inside the jacket, records the temperature of the rod. [Sometimes two thermometers, one near the entrance end P_1 while another near the exit end P_2 are employed to have a mean rise of temperature of the jacket.] There are two travelling microscopes M_1 and M_2 at the two ends of the rod, by which the scratch marks S_1 and S_2 at the two ends can be respectively focussed. The microscope can move parallel to the axis of the rod. The arrangement is shown in Fig. 24.

Theory : The coefficient of linear expansion of a material is the increase in length of unit length of the material for its rise of temperature of 1°C. If x be the increase in length of a rod of length l for a rise of temperature of $t=(t_2-t_1)^\circ C.$, the coefficient of linear expansion of the rod is given by,

$$\alpha = x/(l\,t) = x/l\,(t_2 - t_1) \quad \dots \quad \dots \quad \dots \quad (1)$$

where $t_1{}^\circ C$ and $t_2{}^\circ C$ are the initial and final temperatures of the rod.

Procedure : (*i*) The rod is taken out of the jacket and the *distance between the two scratch marks* at the two ends is measured thrice by a metre scale and its mean value is taken. [If the rod cannot be taken out of the jacket, then the distance between the two scratch marks is to be measured by a beam compass.] Thus we get l.

(*ii*) The rod is introduced inside the jacket and a thermometer T is also inserted inside the jacket through a hole bored in a rubber cork closing the mouth of the tube E of the jacket. The cross-wires of the microscopes M_1 and M_2 are sharply focussed by moving the focussing lens in or out. The microscope tubes are then raised or lowered as a whole, until the two scratch marks S_1 and S_2 are sharply focussed by avoiding parallax between the scratch and the cross-wire. One of the cross-wires of each microscope is then made coincident with one edge of each of the scratch marks. The readings of the scale and vernier attached to each microscope are noted for two successive intervals only (each interval being 2 minutes). The thermometer reading (t_1°C) is also noted.

(*iii*) The steam is then passed inside the jacket and after waiting for some time the reading of the thermometer will be found to be stationary at nearly 99°C. At this time two microscopes are shifted parallel to the axis of the rod and for each microscope the same cross-wire is made coincident with the same edge of the scratch as before. Now the reading of the thermometer as well as the readings of the scale and vernier attached to each microscope are noted after an interval of 2 minutes, until the final readings of the thermometer and those of the scale and vernier attached to two microscopes do not alter for at least 3 consecutive intervals.

(*iv*) If t_1°C and t_2°C are respectively the initial and final steady temperatures of thermometer, then the rise of temperature is (t_2-t_1)°C [When two thermometers (T_1 and T_2) are employed, the rise of temperature indicated by each thermometer should be separately noted. The mean of these two rises of temperature should be employed to calculate α]. If x_1 be the difference between the initial and final constant readings of the left-hand microscope while x_2 be that for the right-hand microscope, the total expansion of the rod is $x = x_1 + x_2$. Knowing, l, x and $(t_2 - t_1)$, we can find α from the relation (1).

Experimental data :

(A) *Determination of the length (l) of the rod :—*

$$l = \frac{(i)\ldots + (ii)\ldots + (iii)}{3} = \cdots\text{cms.}$$

(B) *Determination of the vernier constants of microscopes and noting the readings :—*

Left-hand microscope :

Smallest scale division = ... mm.
...v.d. = ...s.d.
∴ 1 v.d. = ...s.d.
= ...mm.
$v.c. = 1$ s.d. $- 1$ v.d.,
or $v.c. = \ldots$mm.,
or $v.c. =$ *cm.*

Right-hand microscope :

Smallest scale division = ···mm.
...v.d. = ...s.d.
∴ 1 v.d. = ...s.d.
= ...mm.
$v.c. = 1$ s.d. $- 1$ v.d.,
or $v.c. = \ldots$ mm.,
or $v.c. = \ldots$cm.

Stage of Expt.	Time in mins.	Temp. of rod in °C shown by,		Readings for *L.H. microscope* in cm. of,			Readings for *R.H. microscope* in cm. of			Expansion towards *left* $= x_1 = (R_1 \sim R_2)$	Expansion towards *right* $= x_2 = (R_3 \sim R_4)$	Total expansion $= x = x_1 + x_2$
		T_1	T_2	Scale (S)	Vernier $(V) = (v.r.) \times (v.c.)$	Total $= (S+V)$	Scale (S)	Vernier $(V) = (v.r.) \times (v.c.)$	Total $(S+V)$			
Before steam is passed	0	...	...	...	(...) × (..) = ...	...	...	(. .) × (..) = ...	...	... cm.	... cm.	... cm.
	2	... $= t_1$	... $= t'_1$	,,	,,	,, $= R_1$	,,	,,	,, $= R_3$			
When temps. are steady	0				(...) × (..) = ...	...	...	(. .) × (..) = ...	...			
	2	...	...	...	,,	,,	,,	,,	,,			
	4	...	...	,,	,,	,,	,,	,,	,,			
	6	...	...	,,	,,	,,	,,	,,	...			
		... $= t_2$	... $= t'_2$	,	,,	,, $= R_2$			$= R_4$			

Calculation :

Rise of temp. shown by 1st thermometer $T_1 = t' = (t_2 - t_1)$

„ „ „ „ „ 2nd „ $T_2 = t'' = (t'_2 - t'_1)$

Mean rise of temp. $= t = (t' + t'')/2 =$ ... °C.

$\alpha = \frac{x}{lt} =$ ... = ... per°C.

Precautions : (*i*) The microscope is to be *moved parallel to the axis of the tube* so that the shift of the microscope may become equal to the expansion of the rod.

(*ii*) Care is to be taken not to disturb the experimental tube after the passage of steam.

(*iii*) Care is to be taken to take water in the boiler neither too large nor too small.

(*iv*) Focussing of the cross-wire and scratch should be such that there is *no parallax* between their images.

(*v*) If two thermometers are inserted, the initial and the final readings of both the thermometers are to be separately noted, from which the rise of temperature for each thermometer is to be found out. The mean of these two 'rise of temperature' gives *t*.

Oral Questions and their Answers

1. Define coefficient of linear expansion. Does its value depend on the unit of length and scale of temperature ?

For definition see theory. It does not depend on the unit of length, for it is the ratio of two lengths. It depends on the scale of temperature employed, greater in °*C* than in °*F*.

2. Is the expansion for 1°*C* rise of temperature the same at all parts of the scale of temperature ?

No : the value slightly differs and we get the mean coefficient of expansion within the range of temperature which is employed for experiment.

3. What precautions would you take in focussing the microscope ?

First the cross-wire should be sharply focussed by moving the focussing lens in and out and the microscope tube should then be raised or lowered as a whole until the scratch mark is sharply seen and there is no parallax between the cross-wire and the scratch mark on the rod.

4. When will you stop in recording the microscope reading ?

Recording should be stopped when the final readings of the microscopes remain steady for at least five minutes.

5. Will the co-efficient of linear expansion depend on the length of the rod ?

No : it depends only on the material of the rod. If the rod be longer, the expansion is greater.

(b) By optical lever.

Apparatus : The apparatus is shown in Fig 25. This consists of a metal rod *R*, about a metre long, and is surrounded by steam jacket *J* having an inlet tube *I* and an outlet tube *O* for steam. There are two other side tubes for the insertion of two thermometers T_1 and T_2. The lower end of the rod rests on a plate of slate *S* fixed to the base of the frame *FF* in which the steam jacket with the rod *R* in it is fixed vertically. The upper end of the rod passes through the central hole of a glass plate *G* fixed to the top of the frame and projects a little above the glass plate. One leg of an optical lever is placed on the top of the rod, while the other two legs rest on the glass plate.

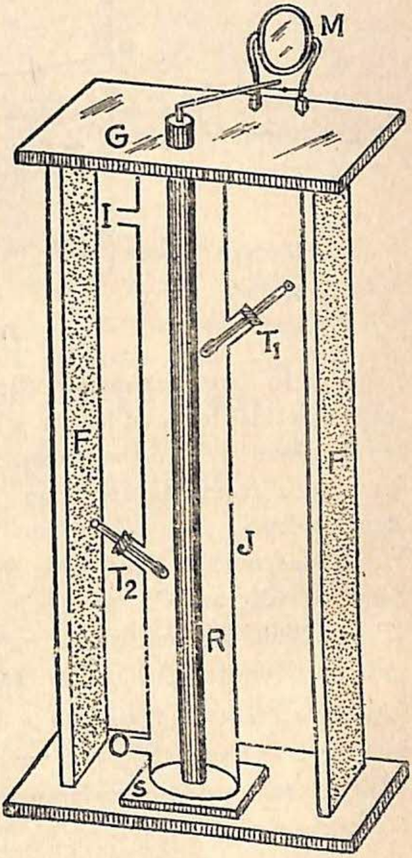

Fig. 25

An optical lever consists of an isosceles-triangled metal frame having three short legs at the three corners. The leg at the vertex rests on the top of the rod, while a small plane mirror *M* with its plane vertical is attached over the other two legs fixed at the two ends of the base of the isosceles-triangled frame.

Theory : If x be the increase in length of a rod of length l due to its rise of temperature from t_1°C. to t_2°C., then the co-efficient of linear expansion is given by $\alpha = x/l(t_2 - t_1)$. If the change of the temperature $(t_2 - t_1)$ be taken as t then

$$\alpha = \frac{x}{lt}. \qquad \ldots \qquad \ldots \qquad \ldots \quad (1)$$

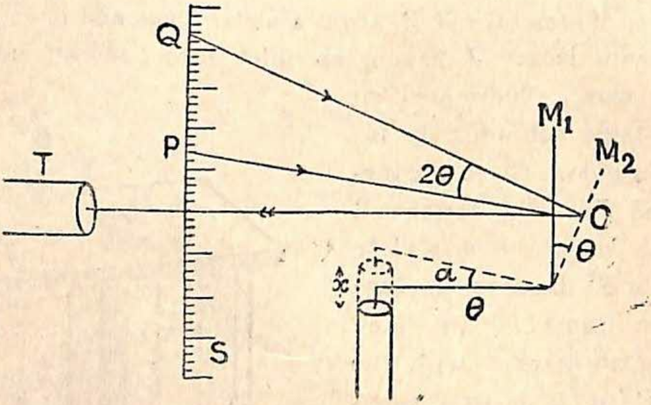

Fig. 26

Due to this expansion of the rod by a length x, let the arm of the optical lever of length a rotate by an angle θ. The mirror, fixed normally to the lever, also rotates by the same angle θ and goes from the position M_1 and M_2 [Fig. 26]. Hence we have $\theta = x/a$ ... ... (2)

Rays from the two points P and Q of the scale S, after reflection from M_1 and M_2 positions of the mirror, enter the telescope T (Fig. 26). The scale and the telescope are kept in front of the mirror. Hence $\angle POQ = 2\theta$. If d_1 and d_2 be the readings of the scale corresponding to the points P and Q, the displacement of the scale image is $d = d_1 \sim d_2$. If D be the perpendicular distance between the scale and the mirror, then

$$2\theta = \frac{d}{D}, \text{ or } \theta = \frac{d}{2D}. \qquad \ldots \qquad \ldots \quad (3)$$

From (2) and (3) we get, $x = a\theta = \dfrac{ad}{2D}$.

$$\therefore \qquad \alpha = \frac{ad}{2Dlt} \qquad \ldots \qquad \ldots \qquad \ldots \quad (4)$$

Procedure : (*i*) The rod is taken out of the steam jacket and its length is measured by a metre scale thrice. The mean of these three readings gives the length (l) of the rod.

(*ii*) The rod is replaced in its position and the optical lever is placed with its mirror vertical so that its leg at the vertex may rest at the middle of the projected end of the rod.

(*iii*) Two thermometers T_1 and T_2 are introduced in the two holes of the steam jacket. Sometimes a single thermometer is introduced into either of the two holes in the steam jacket. A metre scale is then placed vertically in front of the mirror at a distance of about 1 metre from it. The image of the scale in the mirror is focussed by telescope, whose *cross-wire has already been sharply focussed* by the eyepiece. Then the parallax between the images of the cross-wire and the scale is completely eliminated.

(*iv*) The readings of the scale, at which the horizontal cross-wire of the telescope coincides, as well as the reading of the thermometer are simultaneously noted for two times after an interval of 2 minutes. [When two thermometers are inserted in the steam jacket, the initial temperatures of both the thermometers are to be noted . Let the steady readings of the scale and of the thermometer be d_1 cm. and t_1°C respectively.

(*v*) Steam is then passed in the jacket and the readings of the thermometer and of the scale image are observed frequently, until the final readings of the thermometer and of the scale image are nearly steady. At this time the readings of the thermometer as well as of the scale image are to be noted after an interval of two minutes, until the final readings of both the thermometer and the scale image remain constant for at least three consecutive intervals. Let d_2 cm. be the steady reading of the scale image and t_2°C be the final constant temperature. Displacement of the scale image is given by, $d=(d_1 \sim d_2)$ and rise of temperature is $t=(t_2-t_1)^\circ C$. [When two thermometers are taken, the final readings of both the thermometers are to be separately noted. From each thermometer $(t_2 - t_1)$ should be determined and the mean of these two values gives the actual value of $(t_2 - t_1)$].

(*vi*) The distance between the scale and the mirror is measured by a scale along a horizontal line. Thus we get D.

(*vii*) An impression of the supporting pointed legs of the optical lever is made on a paper, and when the imprint of the three legs (1, 2, 3) are joined, we get an isosceles triangle [Fig. 26(*a*)]. The length of the perpendicular drawn from the vertex to the base of this isosceles triangle gives the arm a of the optical lever. Knowing all the quantities, we can find α from the relation (4).

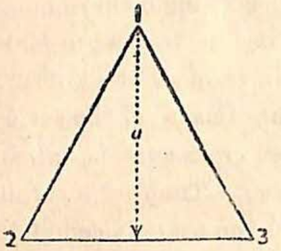

Fig. 26(*a*)

Experimental data :

(A) *Length of the rod* (l) :—

$$l = \frac{\cdots + \cdots + \cdots}{3} = \cdots \text{cm.}$$

(B) *Time-Temperature—Scale reading records* :—

Stage of Expt.	Time in minutes	Temp. of the rod in °C shown by		Scale readings in cm.	Diff. of 1st and last scale reading $= d = (d_1 \sim d_2)$	Temp. difference $= t$ in °C.	Distance between the mirror and scale D.
		T_1	T_2				
Before steam is passed	0 2	... ,, $=t_1$	... ,, $=t'_1$	... ,, $=d_1$	...cm.	(*i*) $t' = (t_2 - t_1)$ $= ..$ (*ii*) $t'' = (t'_2 - t_1')$ $= ...$ Mean, $t = \frac{t' + t''}{2}$ $= ...$	...cm.
When the temps. are steady.	0 2 4 6	... ,, ,, ... $=t_2$	... ,, ,, ... $=t'_2$	... ,, ,, ... $=d_2$			

(C) *Arm of the optical lever* (a) :—

Arm of the optical lever, as obtained by measuring the length of the perpendicular from the vertex 1 on the (2—3) line [Fig. 26(a)] is

$$a = \frac{\cdots + \cdots + \cdots}{3} = \cdots \text{cm.}$$

Calculation :

$$\alpha = \frac{ad}{2Dlt} = \cdots = \cdots \text{per}^\circ C.$$

Precautions : (i) The scale is to be placed at an appreciable distance from the mirror, so that the displacement of the scale-image may be greater.

(ii) Focussing of the cross-wire and the scale-image is to be so made that there is no *parallax* between them.

(iii) No part of the apparatus is to be disturbed when the readings are recorded.

(iv) As far as possible, the axis of the telescope should be in line with the arm of the lever, *i.e.*, in level with the lower edge of mirror ; otherwise the deductions for optical lever will be inaccurate to some extent. *The arm of the lever should be measured very accurately.*

(v)—See item (iii) of Expt. 26(a).

(vi)—See item (v) of Expt. 26(a).

Oral Questions and their Answers

1-2. Same as in microscope method (Expt. 26(a)].

3. As the coefficient of linear expansion α, involves the arm of the lever (a) and distance of the mirror (D), how will α be influenced by their variation ?

Nothing : α depends only on the material of the rod. Increase of the arm a will decrease the value of the displacement of the scale image (d), while an increase of D will cause an increase of d.

4. Why do you take a time-temperature record ?

To show that the temperature has attained a steady value and the constant reading of scale-image signifies that the expansion is complete.

5. Same as in microscope method [Expt. 26(a)].

27. Determination of the coefficient of apparent expansion of a liquid by weight thermometer.[*]

Apparatus : The weight thermometer consists of a glass bulb G having a capillary neck N. This bulb can be introduced into a hot liquid bath B. A thermometer T, reading 1/10°C, records the temperature of the hot liquid in the beaker B. The neck N of the bulb can be introduced, when necessary, into the given liquid taken in another small beaker B_1. The arrangements are shown in Fig 27.

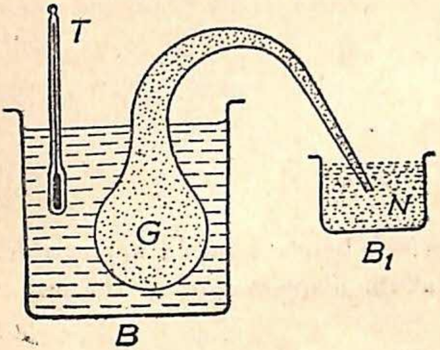

Fig. 27

Theory : Let v_1 & v_2 = internal volumes of the bulb G at room temperature t_1°C and at higher temp. t_2°C,

m_1 & m_2 = masses of the liquid which fill the bulb completely at t_1°C and t_2°C,

ρ_1 & ρ_2 = density of liquid at t_1°C and t_2°C,

γ & g = co-efficients of real expansion of the liquid and of the vessel.

$$\text{Hence } \frac{m_1}{m_2}=\frac{v_1\rho_1}{v_2\rho_2}=\frac{v_0(1+gt_1)}{v_0(1+gt_2)}\times\frac{\rho_0(1+\gamma t_2)}{\rho_0(1+\gamma t_1)}$$

$$\left[\because\ \rho_1=\frac{\rho_0}{1+\gamma t_1}\right].$$

$$=\frac{1+\gamma(t_2-t_1)}{1+g(t_2-t_1)},$$

or,
$$\frac{m_1-m_2}{m_2}=\frac{(\gamma-g)(t_2-t_1)}{1+g(t_2-t_1)}=\frac{\gamma'(t_2-t_1)}{1}.$$

---

[*] Instead of a weight thermometer, an ordinary specific gravity bottle may be conveniently employed which also gives (as is seen by expt.) a satisfactory result.

Here $\gamma - g = \gamma'$ = coefficient of apparent expansion of liquid and g being very small, the term $g\ (t_2 - t_1)$ is neglected.

$$\therefore \quad \gamma' = \frac{m_1 - m_2}{m_2(t_2 - t_1)}. \qquad \ldots \qquad \ldots \ (1)$$

Procedure : (*i*) The mass (w_1) of the empty bulb G is determined by a balance.

(*ii*) The bulb G is then completely filled with the given liquid either by the ordinary process of pouring (when the neck N is wide, as in the case of a sp. gr bottle) or by the repeated heating and cooling process (when the neck N is made capillary) by introducing the neck N always inside the liquid taken in the beaker B_1.

(*iii*) The bulb G, filled with the given liquid, is kept suspended inside an empty beaker B by a fine bare wire attached to its neck, while its neck N is kept immersed in the given liquid in the beaker B_1. The beaker B is then filled with room-temperature water and this water is constantly replaced by fresh water until the thermometer T records a steady temperature of t_1°C, for at least 5 minutes. The bulb G is now taken out of the water in the beaker B by holding it by the suspension wire (the neck N being no longer in the liquid of beaker B_1) and any water on the outer surface of G is wiped out by a clean cloth or blotting paper. The mass (w_2) of the bulb with the liquid in it is determined by a balance. The difference between this mass and the mass of the empty bulb [i.e. $(w_2 - w_1)$] gives the mass (m_1) of the liquid filling the bulb at room-temperature t_1°C.

(*iv*) The bulb G is again introduced in the water of the beaker B and this water is raised to a definite temperature t_2°C (which may be the boiling point of water). When this temperature t_2°C remains steady for at least 5 minutes, the bulb G is taken out by holding it by the suspension wire and again the mass of the bulb with the liquid in it is determined after bringing the bulb and liquid in it at room-temperature t_1°C and wiping out all waters on the outer surface of G. The hot bulb can be brought to room-temperature by keeping it immersed in room-temperature water for sometime. By taking the difference between this mass and the mass of the empty bulb we get the mass (m_2) of the liquid which fills the bulb completely at t_2°C, but partially when brought to room-temperature t_1°C.

(v) Knowing m_1, m_2, t_1 and t_2 we can calculate γ', the mean coefficient of apparent expansion of the given liquid between t_1°C and t_2°C, by employing the relation (1)

Experimental data :

Mass of empty bulb $= w_1 =$ .. gms.

Temp. of liquid in the bulb in °C	Mass of bulb & liquid filling the bulb at the given temp. in gms. 'w_2'	Mass of liquid filling the bulb at the given temperature in gms. $(w_2 - w_1)$	Mass of liquid expelled for the rise of temp. $(t_2 - t_1)$°C. in gms. $= (m_1 - m_2)$	$\gamma' = \frac{m_1 - m_2}{m_2(t_2 - t_1)}$
...$(= t_1$°$)$	...	...$(= m_1)$	...	...
...$(= t_2$°$)$	...	...$(= m_2)$		

[Details of the weights added on the pan should be entered in the table].

Calculation :

$$\gamma' = \frac{m_1 - m_2}{m_2(t_2 - t_1)} = \quad \cdots \quad \cdots \quad = \quad \cdots \text{ per } {}^\circ C.$$

Discussions : (i) As a portion of the neck of the bulb projects above the bath, the temperature of the projecting neck is below that of the bath and hence a small error will come in the result. For this reason, the projecting length should be as small as possible.

(ii) The bulb should not be suspended by thread which may contain water of different amounts at different times causing a change in weight. The bulb should be suspended by a bare thin wire.

(iii) Before taking any weight, the bulb with the liquid in it must be brought to room-temperature and any liquid on the outer surface of the bulb and the suspension wire should be wiped out.

(*iv*) If the variation of the coefficient of apparent expansion of the liquid with temperature is wanted, the bulb G is to be maintained at different temperatures between t_1°C. and t_2°C (the boiling point of water) by steps of 10°C. In each case, the mean coefficient of expansion within the interval of temperature of 10°C. is to be calculated and the mean temperature of that interval is to be found out. Then a graph is to be drawn with the coefficient of apparent expansion within the interval as the ordinate and the mean temperature of the interval as abscissa. This graph will indicate the variation of the coefficient of apparent expansion with temperature.

Oral Questions and their Answers

1. What is the name of your apparatus and why is it so called?

The name of the apparatus is weight thermometer; it is so called because by knowing the masses m_1 and m_2 of the liquid which fills the thermometer at 0°C. and t°C. respectively, we can determine an unknown temperature t°C from the relation, $\gamma' = \frac{m_1 - m_2}{m_2 t}$, provided the coefficient of apparent expansion γ' is known.

2. What is the distinction between real and apparent expansion of a liquid?

Real expansion of a liquid is its actual expansion when it is alone heated while the apparent expansion of liquid is its expansion which is observed relative to that of the containing vessel.

3. What quantity you would measure by this instrument? The mean coefficient of apparent expansion between two given temperatures.

4. What do you mean by the term 'mean coefficient' of apparent expansion?

The expansion of the liquid as well as that of the vessel are not the same at all temperatures. Hence we get the average or mean coefficient of apparent expansion between two given temperatures.

5. Can you find the coefficient of linear expansion of the material of your weight thermometer by this arrangement?

Yes, the relation between the coefficient of real expansion (γ), the coefficient of apparent expansion (γ') and the coefficient of cubical expansion (g) of the vessel is given by, $\gamma = \gamma' + g$. Knowing γ and finding γ' by this experiment, we can calculate g and hence the coefficient of linear expansion would be $\alpha = g/3$.

6. Can you suggest any modification of your apparatus by which you can determine directly the coefficient of real expansion of the liquid?

If the bulb of the thermometer initially contains mercury whose

Procedure : (*i*) The apparatus is levelled so that the tubes *CD* and *EF* are vertical and the cross-tubes are horizontal.

(*ii*) At first, air at room-temperature t_1°*C* is allowed to remain in both the jackets or cold water is passed through both the jackets for some time when the thermometers T_1 and T_2 will give the same reading t_1°*C*. (room-temperature) and the difference of mercury levels in the tubes *BA* and *GK* will be observed to be nil. If the initial readings of T_1 and T_2 differ then these readings are to be noted.

(*iii*) A cathetometer is adjusted so that its pillar is vertical and the axis of the telescope is horizontal. The cross-wire of the telescope is sharply focussed by moving the focussing lens in or out. The vernier constant of the cathetometer scale is also found out.

(*iv*) The space inside the jacket J_1 is kept at room temperature t_1°*C* either by allowing air at room-temperature to remain in it or by allowing room-temperature water to circulate in J_1. Water from the tube *T* is allowed to fall drop by drop on the blotting papers P_1 and P_2 and instead of cold water in the jacket J_2, steam is now passed in it. As the temperature recorded by T_2 increases, the mercury level in tube *GK* is found to rise. After some time, when the mercury meniscus in the tube *GK* remains steady the horizontal cross-wire of the cathetometer telescope is made tangential to the convex surface of this meniscus and the readings of the cathetometer scale and vernier as also of the thermometers T_1 and T_2 are noted. From this time onward, the readings of the vernier and of the two thermometers are noted after an interval of 5 minutes. If the meniscus in the tube *GK* moves past the cross-wire, the reading of the vernier is to be taken after raising the telescope and making the horizontal cross-wire tangential to the convex surface of mercury meniscus. Recording of these readings of the vernier and the two thermometers are to be continued until they remain steady for at least two consecutive intervals (*i.e.* for 10 minutes). Let this final reading of the vernier be R_2.

The horizontal cross-wire is then made tangential to the convex meniscus of mercury in the tube *BA* and the reading R_1 of the vernier is noted. Hence the difference of mercury levels in the tubes *GK* and *BA* is obtained as $x=(R_2 \sim R_1)$. [When a cathetometer scale is employed to measure the difference of mercury levels in *BA* and *GK*, the glass scale placed behind *BA* and *GK* is to be considered absent.]

(*v*) The distance H between the axes of the cross tubes *CF* and *DE* is measured by a metre scale or by the cathetometer.

(*vi*) γ is calculated from the relation (1) by substituting the values of H, x, t_2 and t_1.

Experimental data :

(A) *Determination of the vernier constant of the cathetometer scale and noting the difference of mercury levels* (x) :—

Value of 1 smallest division of the scale = ... mm.

... *v.d.* = ... *s.d.*

1 *v.d.* = ... *s.d.* = ... mm.

$\therefore$ *v c.* = (1 *s d.* − 1 *v.d.*) = (···) − (···) = ... cm.

Stage of Expt.	Time in minutes	Temp. in°C of		Meniscus readings in cm. of,						$x=(R_1 \sim R_2)$ in cm.	Value of γ
				Cold limb			Hot limb				
		Cold limb (t_1)	Hot limb (t_2)	Scale (S)	Vernier $V=(v.r.)\times(v.c.)$	Total $=R_1=(S+V)$	Scale (S)	Vernier $V=(v.r.)\times(v.c.)$	Total $=R_2=(S+V)$		
When both limbs are at room temp.	0	...	...	...	(...)×(...)	...	...	(...)×(...)	...	0	
	5	,,	,,	,,	,,	,,	,,	,,	,,	,,	
When one limb is at room temp. while steam flows at the other limb.	0	...	...	...	(...)×(...)	...	...	(...)×(...)	...	...	....
	5	,,	,,	,,	,,	,,	,,	,,	,,	,,	per °C
	10	,,	,,	,,	,,	,,	,,	,,	,,	,,	

(B) *Distance (H) between the axes of two horizontal cross-tubes* :—

$$H=\frac{(i)\cdots+(ii)\cdots+(iii)\cdots}{3}= \quad \ldots \quad \ldots \quad \text{cm.}$$

Calculations :

$$\gamma=\frac{x}{(H-x)(t_2-t_1)}= \quad \ldots \quad = \quad \ldots \text{ per}^\circ C.$$

Discussions : (*i*) The two tubes *BA* and *GK* must be of identical cross-section, otherwise at room temperature the mercury levels in them will not give indentical readings due to the effect of surface tension.

(*ii*) The length *H* of the two vertical arms cannot remain the same when they are at different temperatures and hence the simple formula of (1) will not hold good.

(*iii*) The ideal condition of no-mixing of hot and cold liquids will never be secured and hence error will be introduced.

(*iv*) Readings of the mercury meniscus should be taken after avoiding parallax between the cross-wire and the image of meniscus.

(*v*) The blotting papers are to be soaked constantly with water so that the flow of heat from hotter to the colder parts of mercury may be prevented as much as possible.

Oral Questions and their Answers

1. Define co-efficients of real and apparent expansion of a liquid and state the relation between them.

The coefficient of real expansion (γ) of a liquid is the ratio of the increase in volume of a liquid when it is alone heated by 1°C to its original volume at 0°C.

The coefficient of apparent expansion (γ') of a liquid is the ratio of the observed increase in volume of a liquid when both the liquid and the containing vessel are heated by 1°*C*. to the original volume of the liquid at 0°C.

The relation between γ and γ' is, $\gamma=\gamma'+g$; where g is the coefficient of cubical expansion of the material of the vessel.

2. What is the harm if the tubes *BA* and *GK* be not of identical cross-section ?

Due to capillarity, a difference of level will be created even when the mercury in the two vertical arms *CD* and *FE* are at the same temperature.

3. Will the meniscus of liquid within the tubes be convex for all liquids ?

No ; the meniscus will be convex upward for those liquids which do not wet glass but it will be concave upward for those liquids which wet glass.

4. Will the cross-section of the tubes CD and EF affect the difference in level ?

Difference in level will be dependent on the temperature difference of the two arms and not on the cross-section of the tubes, provided they are appreciable. Thus the expansion of the vessel does not affect the result.

29. Determination of the pressure-coefficient of a gas at constant volume.

Apparatus :—The apparatus is shown in Fig. 29. It consists of a large glass globe A, kept immersed in a beaker of

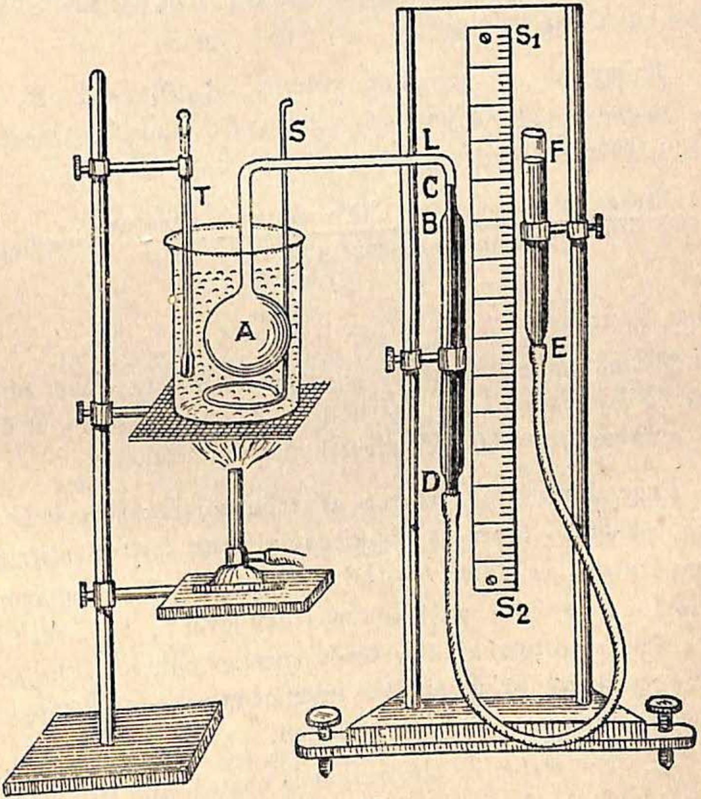

Fig. 29

water containing a thermometer T and a stirrer S. The globe A

is connected to a wide glass tube BD by a capillary tube bent twice at right angles and having a mark at C. The lower end D of the tube BD is connected to the lower end E of another wide tube EF by a thick-walled India-rubber tube. The tubes BD and EF can be independently raised or lowered or can be clamped at any position. Part of the tube EF, the whole of the rubber tube and of the tube BD and a part of capillary tube up to the mark C contain pure and dry mercury. The mercury level in BD should always be kept at C either by raising or by lowering the tube EF so that the volume of the gas remaining in the globe A and in the capillary tube may be kept constant. By a vertical scale S_1S_2, fixed on the wooden stand, the position of mercury level in EF as well as the constant position of mercury level at C can be noted.

Theory : At constant volume, if P_t and P_0 are the pressures of a given mass of a gas at $t°C$. and $0°C$. respectively, then according to gas laws,

$$\frac{\text{Increase in pressure for } 1^\circ C. \text{ rise of temperature}}{\text{Original pressure at } 0^\circ C.} = \alpha \text{ (constant)}$$

$$\text{or,} \quad \frac{P_t - P_0}{P_0 t} = \alpha \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

From the relation (1) pressure-coefficient α can be determined by knowing P_0, P_t and t. The pressure P_0 at $0°C$. can be obtained from $(P-T)$ curve by extrapolation.

Procedure : (*i*) Water at room-temperature is poured in the beaker to cover the bulb completely. After stirring, its temperature is noted by the thermometer T. The arm EF is raised or lowered until the mercury level in the arm CD is at C. The readings of the scale corresponding to the constant mercury level at C and the level of mercury in EF are noted. The barometric height is also noted.

(*ii*) The water in the beaker is heated and its temperature is raised by steps of $10°C$. and at each stage the temperature is maintained constant for about 5 minutes, as far as practicable, by the proper manipulation of the burner. Due to the rise of temperature of the gas in the bulb A, the mercury level in CD will be depressed below C. The arm EF is now raised to bring the mercury level in CD again at the constant mark C. The readings of the scale corresponding to the free surface of mercury in EF and CD are noted. [For convenience in taking readings of the scale, a set square may be employed whose one edge will be kept parallel to the length of the scale while the right-angled edge may be kept tangential to the mercury surface.] This observation is repeated for six different temperatures.

(*iii*) The barometric height at the end of the experiment is to be noted and the mean of the initial and the final barometric heights is to be found out. Let it be H cms. of mercury.

(*iv*) The difference of the scale readings (h) corresponding to the constant mercury level at C and the mercury level in EF is to be determined at each temperature and the gas pressure is given by $(H \pm h)$ cms. of mercrry. Pressure of the gas would be $(H+h)$ or $(H-h)$ according as the mercury level in EF is above or below the constant mercury level at C.

(*v*) A graph is then drawn in which temperature is plotted along the x-axis having zero as the origin, while pressure is plotted along the y-axis. A best straight line is drawn through the points and it is produced to cut the y-axis at a point, the value of whose ordinate gives P_0. Taking *any point on the graph*, P_t and t corresponding to this point are found out and α is determined from the relation (1) by putting the values of P_0, P_t, and t.

Experimental data :

(A) *Barometric height* (H) :—

Smallest division of the main scale = ... cm.

... *v d.* = ... *s.d.*

Vernier constant ($v.c.$) = $(1\ s.d. - 1\ v.d.) = \cdots s.d. = \cdots\ cm.$

TABLE I

Time of record	Barometric height			
	Scale reading in cm. (S)	V. reading in cm. $(V)=(v.r.)\times(v.c.)$	Total Reading in cm. $H=(S+V)$	Mean height (H) in cm.
Before Expt.	...	(...)×(...) = ...	...	...
After Expt.	...	(...)×(...) = ...	...	

(B) *Pressure-temperature record* :—

TABLE II

No. of Obs.	Temp. in °C	Readings in cm. of the mercury level in the		Difference of two levels in cm. $h=(R_1\sim R_2)$	Pressure of gas in cms. of mercury $P=H\pm h$.
		Open limb (R_1)	Closed limb constant level (R_2)		
1	27	...	....	...	...
2	37	...	,,	—	...
etc.	etc.	etc.	,,	etc.	etc.
7	87	...	,,	...	...

N.B. [Value of h should be added to or subtracted from H according as mercury level in open limb is higher or lower than, that in the closed limb.]

(C) *Drawing of $(P-t)$ graph from a sample data of Table III* :—

TABLE III

Temp. in °C →	27	37	47	57	67	77	87
Press. of gas in cms. of mercury →	79·2	81·8	84·3	86·9	89·4	91·9	94·5

To draw pressure-temperature graph, the temperature in °C is to be plotted along x axis with $0°C$. as the value of origin,

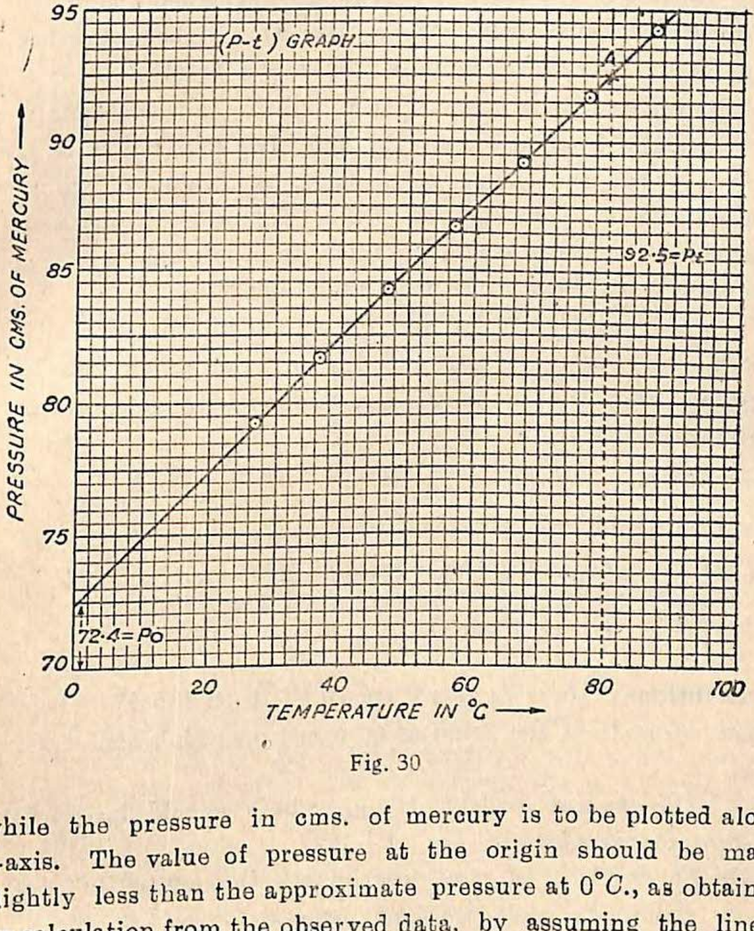

Fig. 30

while the pressure in cms. of mercury is to be plotted along y-axis. The value of pressure at the origin should be made slightly less than the approximate pressure at $0^{\circ}C.$, as obtained by calculation from the observed data, by assuming the linear variation of pressure with temperature under constant volume.*

N. B. *[Selection of origin for the P-axis should be made from the given data of Table III, as follows : Increase of pressure for a rise of temp. of $(87-27)=60^{\circ}C$. is $(94{\cdot}5-79{\cdot}2)=15{\cdot}3$ cm. Hence the fall of pressure for $27^{\circ}C=\frac{15{\cdot}3\times 27}{60}=6{\cdot}89$ cm.

Thus, $P_0=(79{\cdot}2-6{\cdot}89)=72{\cdot}31$ cm. nearly. The origin of pressure along the pressure-axis should be made equal to 70 cm. while the origin of temperature along the temp.-axis should be 0°C.]

The difference between the pressure at the origin and the pressure which is slightly higher than the highest pressure in the data, is to be distributed over the total number of divisions available along y-axis. After plotting all the points, a best straight line is drawn through the points and it is produced to cut the y-axis at a point, the value of whose ordinate gives P_0 (pressure at 0°*C*.). Taking any point A on the graph (*which is not within the data*), the co-ordinates (t, P_t) of this point A are determined from the graph [Fig. 30].

When the values P_t, t and P_0 are put in the relation (1) we get the value of α. The way of drawing the graph can be understood from the graph of Fig. 30 drawn from the sample data shown in Table III.

Calculation :

P_0 (from graph) = 72·4 cm.

P_t for any temp. 80°*C*. (from graph) = 92·5 cm.

$$\alpha = \frac{P_t - P_0 \ldots}{P_0 t} = \cdots \text{ per}^\circ C.$$

Precautions : (*i*) Temperature of the bath should be kept constant for at least five minutes by proper manipulation of the burner.

(*iii*) The gas introduced in the glass bulb should be made dry before introduction.

(*iii*) At the end of the experiment, the open limb of mercury should be kept *sufficiently lowered, to avoid subsequent suction of mercury* in the bulb.

(*iv*) The temperature of the bath should be raised not very high, otherwise the error in the result will be appreciable due to large difference of temperature between the bath and the dead space (i.e. the space in the capillary tube whose temperature is the temperature of room).

Oral Questions and their Answers

1. Define pressure-coefficient of a gas and state its unit. Does it depend on (*i*) mass, pressure, temperature. and nature of the gas taken, (*ii*) scale of temperature employed ?

For def.—see theory. Its unit is (per °C); (*i*) No; for the ratio of the increase of pressure for 1°C. rise of temperature to the original pressure at 0°C. will remain constant, (*ii*) If the temperature is measured in °*F*., then the value of α will be less.

2. Why is it called thermometer?

Because by measuring pressure P_t at any temp. t°C. we can find t from the relation $P_t = P_0\,(1+\alpha t)$, for α and P_0 being known.

3. Why is it necessary to maintain the temperature of the bath constant for 5 minutes?

Usually the temperature of the gas is less than that of the bath due to the barrier of the glass wall of the bulb. Hence maintenance of constant temperature of the bath for the longer time will ensure equality of the temperature of the gas and the bath.

4. Why the bulb is connected by a capillary tube?

Amount of gas in it, which is at room-temperature, may be as small as possible.

5. Is it desirable to make the constant mark *C* near to or much below the bend at *L*.

Very near to *L*; for in that case, amount of gas at room-temperature may be small.

6. Why do you take mercury for pressure measurement instead of any other light liquid?

As the barometric height (H) is measured in cms. of mercury, it will be easy to measure gas pressure by adding or subtracting the difference (h) of mercury levels in the two arms with H, while for other liquids absolute pressure ($h\rho g$) should be separately determined both for barometric height as well as in this case, and their sum or difference will give the gas pressure.

7. Why do you keep the volume of the gas constant?

Pressure will vary linearly with temperature provided the volume is kept constant.

8. What will be the harm if the gas is moist?

For, moisture in the gas obeys gas laws approximately so long as it remains unsaturated, but when saturated, gas laws are not obeyed by it.

9. What idea do you get about absolute zero from the experiment?

The value of α obtained by experiment is 1/273. Thus pressure calculated at −273°C. from the relation $P_t = P_0\left(1+\frac{t}{173}\right)$ by putting $t =$ −273°C. becomes zero. Hence −273°C. is taken as the absolute zero.

10. What is dead space and what should be its volume?

There is a small space outside the bulb in which a portion of the gas remains at a temperature lower than that of the gas in the bulb. This space is called *dead space* and the value of this space should be as small as possible.

30. *Determination of the coefficient of expansion of a gas at constant pressure.*

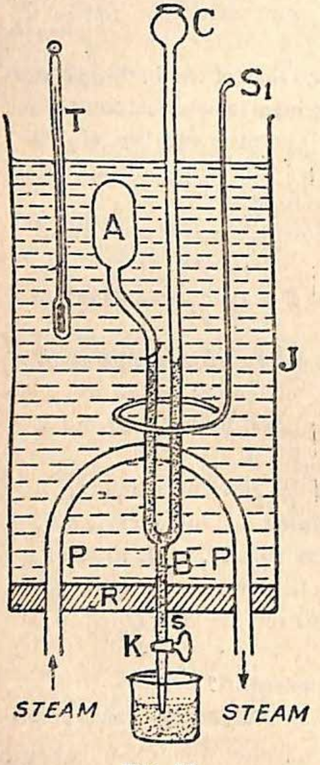

Fig. 31

Apparatus : The apparatus is shown in Fig. 31. It consists of a *U*-tube whose shorter limb *AB* is graduated in c c. and terminates in a bulb *A*. The other longer limb *BC* is open to the atmosphere and terminates in a funnel *C*. A short tube *S*, having a stop-cock *K*, is attached to the bottom *B* of the *U*-tube. The *U*-tube is kept in a large glass jar *J* containing water so that the bulb *A* is below the water surface while the funnel *C* is above the jar. The bottom of the jar is closed by a rubber cork *R* through which the short tube *S* with its stop-cock *K* passes out, so that the stop-cock can be operated from outside. A bent copper tube *P* in the form of an inverted *U* passes through the rubber cork *R* so that the free ends of *P* are outside. By passing steam through this copper tube, water in the jar can be heated. A thermometer *T*, kept suspended in the water near the bulb, records the temperature of water while by the stirrer S_1 this temperature can be maintained uniform throughout the entire mass of water. The *U*-tube *ABC* contains conc. sulphuric acid whose levels in the two arms are always kept in the same horizontal plane either by adding acid through the funnel *C* or by taking away acid by opening the stop-cock *K*.

Theory : At constant pressure, the increase in volume of given mass of a gas for 1°C. rise of temperature bears a constant ratio to its original volume at 0°C. (Charles' law). Hence at constant pressure, if V_t and V_0 are the volumes of a given mass of a gas at t°C. and 0°C. respectively then,

$$\frac{V_t - V_0}{V_0 t} = \alpha \text{ (constant)} \quad \cdots \quad (1)$$

This constant α is called the coefficient of expansion of the gas at constant pressure. From the relation (1) the volume coefficient α can be found out by finding volumes V_0, and V_t of the gas at 0°C. and at any temp. t°C respectively. The volume V_0, will be obtained from ($V - T$) curve by extrapolation.

Procedure : (*i*) Water is taken in the jar J at room-temperature and its temperature is noted by the thermometer T. The volume of the gas is noted after bringing the sulphuric acid levels in the two arms, in the same horizontal plane.

(*ii*) Temperature of the water in the jar is raised by steps of 5°C. by passing steam through the copper tube. At each stage, the temperature of the water is noted after vigorous stirring and maintaining this temperature constant for about five minutes. The volume of the gas is always noted after bringing the sulphuric acid levels in the two arms in the same horizontal plane. Six such observations are recorded.

(*iii*) The barometric height is noted before and after the experiment to see whether the atmospheric pressure is remaining constant or not.

(*iv*) A graph is drawn with temperature along the x-axis having 0°C. as the origin. The volume is plotted along the y-axis having the origin a value, which is slightly less than approximate volume (V_0) at 0°C., as obtained by calculation from the observed data, by assuming the linear variation of volume with temperature under constant pressure.

A best straight line, passing through the points is drawn and it is produced to cut the y-axis at a point whose ordinate gives V_0.

Finding V_t *for any temperature* $t°C$. *from the graph*, α is calculated from the relation (1).

Experimental data :

(A) *Barometric height record :—*

Barometric height before experiment = ... cms.
" " after " = ... "
∴ Barometric height was fairly constant.

(B) *Volume-temperature record :—*

No. of Readings.→	1	2	3	4	5	6
Temp. of bath in °C.→ (t)	room-temp. (t_1)	(t_1+5)	...	...	...	...
Volume of the gas in c.c.→ (V)	...	...	...	...	...	...

N. B. [Temperature should be increased by steps of 5°C.]

(C) *Drawing of* $(V-t)$ *graph :—*

The procedure for drawing the $(V-t)$ graph is similar to that indicated in item (C) of Expt. 29. The only difference is, that instead of pressure, the volume in c.c. should be plotted along y-axis.

Calculation of approximate volume (V_0) at $0°C$. from the given data and the subsequent selection of origin for the volume axis, should be made in the same manner as is indicated in item (C) of Expt. 29. The nature of the $(V-t)$ curve will be the same as that of the $(P-t)$ curve, shown in Fig. 30. Taking any point on this graph (*which is not within the data*), the co-ordinates (t, V_t) of this point are determined. When the values of V_0, V_t, and t are put in the relation (1) we get the value of α.

Calculation :

V_0 (from graph) = ... c.c.

V_t at temperature $t°C$. (from graph) = ...c c.

$\alpha = \frac{V_t - V_0}{V_0 t} =$ ... ... = per °C.

Precautions : (*i*) Care should be taken in pouring or taking away conc. sulphuric acid, so that it may not fall on the body.

(*ii*) Reading of the volume should be taken from the tangent plane of the meniscus after bringing the sulphuric acid levels in the two arms in the same horizontal plane. In that case, the constant pressure of gas will be equal to the atmospheric pressure.

(*iii*) The temperature of the bath is to be kept constant for at least 5 minutes, to be sure that the gas assumes the temperature of the bath.

(*iv*) The temperature should be changed by steps of 5°C. otherwise the number of data available for the drawing of graph will not be sufficient.

(*v*) The maximum temperature of bath should be below 80°C. otherwise the increase of volume of the gas would be so much that a portion of the gas will escape from the closed limb.

Oral Questions and their Answers

1. State Charles' law and define volume coefficient.—See theory.

2. Can you measure temperature by this apparatus ?

Yes, by using the relation $V_t = V_0\ (1+\alpha t)$, we can find an unknown temperature t°C. Knowing V_t we can find t, for V_0 and α are previously determined.

3. How does the experiment lead to the idea of absolute zero ?

The value of α has been found by the experiment as 1/273. Hence the relation between volume and temperature is given by $V_t = V_0 \times \left(1+\frac{t}{273}\right)$. If $t = -273$°C., then $V_t = 0$. This temperature of -273°C. is taken as the zero in constructing the absolute scale of temperature and this zero is called absolute zero.

4. Why do you take sulphuric acid as the manometric liquid ?

It is a light liquid so that a small change of gas pressure will be indicated by a large difference in levels and at the same time the gas is kept dry owing to the hygroscopic property of conc. sulphuric acid.

5. What is the harm, if water be taken as the manometric liquid ?

It will give water vapour in the gas and the pressure of this vapour is appreciable. This water vapour does not obey gas laws and hence the gas should be kept dry by conc. sulphuric acid.

6. What is the harm, if one arm of the U-tube be made wide while the other arm be made narrow ?

There will be a difference in the acid levels in the two arms due to the effect of surface tension, though the free surfaces in the two arms are exposed to the same pressure.

7. Does the volume—coefficient depend on mass, temperature, and volume of the gas ?—No.

8. Will the volume coefficient be different, if the temperature be in °F ?—Yes, it will be smaller.

9. Why do you keep the pressure constant ?

For the volume will vary linearly with temperature when pressure is kept constant.

10. Are the gas laws true for all gases ?

No ; it is approximately true for the so-called permanent gases. The *pressure-volume-temperature relation for a real gas is different from the simple relation employed here.*

31. Determination of the specific heat of a solid or of a liquid by the method of mixture, by applying correction for the loss of heat by radiation.

Apparatus : The apparatus, which is shown in Fig. 32, consists of the following parts :—

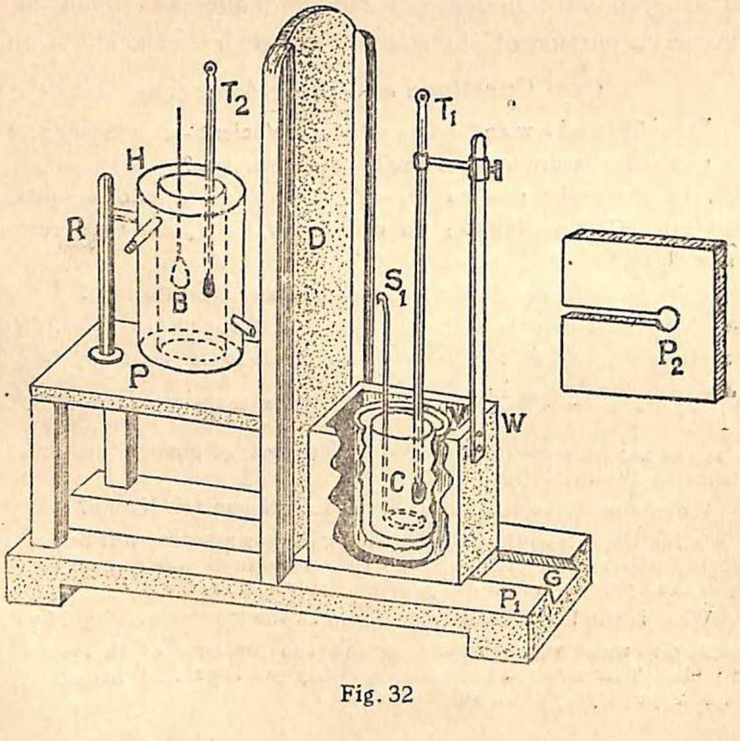

Fig. 32

(i) Steam-Heater (H) :—It consists of two co-axial cylinders of copper in which the top and the bottom of annular space between the two cylinders is entirely closed excepting the two outlets for the entrance and exit of steam. The mouth of the inner cylinder is closed by a cork through which passes a thermometer T_2 reading $(\frac{1}{2})^\circ C$. Through another hole in the cork a string passes, at the lower end of which a solid body B is kept suspended by the side of the thermometer bulb. By this arrangement, the solid is heated in hot air. The steam-heater is hinged to a vertical rod R fixed to a raised wooden platform P with a central hole.

(ii) Calorimeter (C) :—The copper calorimeter C is placed inside another copper vessel V separated from each other by cork pads. Or, in better arrangement, the calorimeter C is kept suspended inside the copper vessel V by three strings attached to the rim of V. The copper vessel V with the calorimeter in it is kept inside a wooden vessel W. The vessels V and W are separated by cotton pads kept in between them. The bulb of a thermometer T_1 reading $\frac{1}{10}{}^\circ C$. is dipped inside the calorimetric liquid and is kept fixed in position by a clamp attached to a vertical stand on the wooden vessel W. The calorimeter also contains a stirrer S_1 by which the liquid in it can be stirred. The calorimeter can slide in a groove G made on the lower horizontal platform P_1. The mouth of the calorimeter can be closed by a slotted wooden cover P_2 (shown separately).

(iii) Sliding partition (D) :—There is a sliding partition D by which the transference of heat from the hot steam-heater to the calorimeter is prevented.

Theory :—If a solid of mass m and specific heat s be heated to a constant high temperature $t_2{}^\circ C$. and then quickly dropped into a calorimeter of mass m_1 and specific heat s_1 containing a liquid of mass m_2 and specific heat s_2 both at $t_1{}^\circ C$., then there will be a common temperature t of the mixture. At this stage, heat lost by solid = heat gained by the calorimeter and its contents ;

or, $ms(t_2 - t) = m_1 s_1 (t - t_1) + m_2 s_2 (t - t_1)$

or, $ms(t_2 - t) = (m_1 s_1 + m_2 s_2)(t - t_1)$ ... (1)

This common temperature (t) of the mixture is usually less than its actual value T due to the loss of heat by radiation. The value of T is to be determined after correcting for the loss of heat by radiation. The corrected relation is then given by,

$$ms(t_2 - T) = (m_1 s_1 + m_2 s_2)(T - t_1)$$

$$\text{or,}\quad s = \frac{(m_1 s_1 + m_2 s_2)(T - t_1)}{m(t_2 - T)} \qquad \cdots \quad (2)$$

$$\text{or,}\quad s_2 = \frac{ms(t_2 - T)}{m_2(T - t_1)} - \frac{m_1 s_1}{m_2} \qquad \cdots \quad (3)$$

The relation (2) is employed to determine the specific heat s of the solid when that (s_2) of liquid is known while the relation (3), is employed to find the sp. heat s_2 of liquid when that (s) of solid is known.

Procedure : (*i*) Nearly half of the boiler is filled with water and two burners are applied below to supply steam to the steam-heater.

(*ii*) The mass m of the solid is determined by a balance and it is kept suspended inside the steam-heater close to the thermometer bulb (reading $\frac{1}{2}$°C.) introduced through the upper cork. The lower end of the steam-heater is now closed by a sliding board on the raised wooden platform.

(*iii*) The clean and dry calorimeter with its stirrer having total mass m_1 is first weighed empty and then again its mass $(m_1 + m_2)$ is determined after taking the liquid in it (whose specific heat is required) sufficient to immerse the solid. From these two weights, the mass (m_2) of the liquid taken is thus known. The calorimeter is then replaced in its position in the copper vessel V. A thermometer reading $\frac{1}{10}$°C. is introduced in the calorimetric liquid and after stirring the liquid, its temperature is noted. Let it be t_1°C.

(*iv*) The temperature of the solid is observed from time to time and when this temperature remains steady for at least five minutes it is noted down. Let it be t_2°C.

(*v*) After taking away the sliding board from the bottom of the steam-heater, it is rotated about its hinge so that it is just above the hole in the raised platform. By raising the sliding wooden partition D, the wooden box W containing the calorimeter is brought just below the hole. The hot solid is then *quickly* dropped into the calorimeter (taking care that no liquid splashes out of the calorimeter) and it is quickly removed to its former position and the wooden partition is dropped down.

(*vi*) The temperature of the calorimetric liquid is recorded after an interval of *half a minute*, beginning from at least 3 consecutive intervals before the introduction of the hot solid and ending when the eight falling temperatures, after the attainment of maximum temperature $t^\circ C.$, are recorded.

(*vii*) Fall of temperature of the calorimeter and its contents by an amount of $x^\circ C$ due to radiation, during the course of attainment of its maximum temperature $t^\circ C$, is then calculated from the observed data and the corrected common temperature is obtained as $T = t + x$.

(*viii*) It is better to draw a graph by plotting the time in minutes along x-axis and the corrected temperature [as obtained in column (6)] along y-axis. A horizontal part will be obtained in the graph. The ordinate of this horizontal part will be the corrected temperature T as is shown in Fig. 34.

Experimental data :

(A) *Recording of weights and other constants :—*

TABLE I

Masses of,				Sp. heat of calr. & stirrer s_1	Sp. heat of solid (s) [or of liq. (s_2)]
Solid m	Calorimeter + stirrer m_1	Calorimeter + stirrer + liq. $(m_1 + m_2)$	Liquid m_2		
.. gm + .. gm. + mg. + ... = 20 2 gms.	... gm. + ... gm. + ... mg. + ... = 108·42 gms.	.. gm. + ... gm. + ... mg. + ... = 200·49 gms.	200·49 − 108·42 = 92·07 gms.	·09	Sp. heat of solid (s) = ·21

(B) *Recording of temperature* (t_2) *of hot solid :—*

TABLE II

Time in minutes→	5	10	15	20	25	30	35	40	45	50
Temps. in °C.→	...	...	...	...	...	...	...	99	99	99

(C) *Time-temperature record* :—

TABLE III

Initial temperature of calorimeter and liquid $= t_1 {}^\circ C = 33^\circ C.$

	1 Time in mins.	2 Temp. (θ) of calorimeter in °C.	3 Average temp. in °C. (θ')	5 Cooling during the interval from cooling curve in °C.	5 Total cooling (y) at the end of interval in °C	6 Corrected temperature in °C. ($\theta + y$)	7 Corrected temperature of the mixture $= T$°C.
Room temp.	0	33 (t_1)					
	½	33 (,,)					
	1	33 (,,)					
		hot solid dropped					
Rising temperatures	1½	34·5	33·75	·009	·009	34·509	
	2	35·5	35	·024	·033	35·533	
	2½	36·7	36·1	·038	·071	36·771	
	3	37	36·85	·047	·118	37·118	
	3½	37·2	37·1	·05	·168	37·368	
	4	37·3	37·25	·052	·220	37·520	
	4½	37·3	37·3	·053	·273	37·573	
Falling temperatures	4	37·2	37·25	·052	·325	37·525	37·55
	5½	37·2	37·2	·052	·377	37·577	
	6	37·1	37·15	·051	·428	37·528	
	6½	37·1	37·1	·05	·478	37·578	
	7	37	37·05	·05	·528	37·528	
	7½	37	37	·049	·577	37·577	
	8	36·9	36·95	·048	·625	37·525	
	8½	36·9	36·9	.048	·673	3·573	

(D) *To find the rate of cooling from Table III* :—

TABLE IV

Interval of two minutes.	Falling of temperature in °C	Cooling for two minutes in °C	Average cooling for ½min. in °C	Average of eight falling temps. of Table III
from 5th to 7th min.	from 37·2 to 37	·2	·05	37 05°C,
,, 5½th to 7½th ,,	,, 37·2 to 37	·2		
,, 6th to 8th ,,	,, 37·1 to 36·9	·2		
,, 6½to to 8½th ,,	,, 37·1 to 36·9	·2		

Explanation of Table III :—(*i*) Column 3 represents the average of a temperature with a temperature next previous to it, *e.g.* 33·75° is the average of 34·5° and its next previous temperature 33°. Again 35° is the average of 35·5° with its next previous temperature 34·5° and so on.

(*ii*) Column 4 represents the cooling of temperature in an interval of time obtained from cooling curve of Fig. 33. The amount of cooling for any average temperature is written by the side of that average temperature, *e.g.* cooling for the average temperature 33·75° is ·009. Again cooling for the average temperature 35° is ·024 and so on.

(*iii*) Column 5 represents the total amount of cooling at any average temperature. In order to determine total cooling at an average temperature, the cooling at that average temperature must be added to the sum of the coolings occurring at all the average temperatures previous to this, *e.g.* the total cooling at the average temperature 36·85° = ·047 + (sum of all the previous coolings) *i.e.* = ·047 + (·038 + ·024 + ·009) = ·047 + ·071 = ·118.

(*iv*) Column 6 represents the corrected temperature at a particular time. This is obtained by adding the temperature at that time with the total cooling, *e.g.* the correct temperature at 3rd minute = 37° + total cooling at that time = 37° + ·118 = 37·118°.

(E) *To draw the cooling curve* :—

(*i*) The rate of cooling at room-temperature (33°*C.*) is zero while the cooling of (·05°*C.*) for ½ min. at the average of the eight falling temperature (37·05°*C.*) is obtained from Table IV. These two points are thus known.

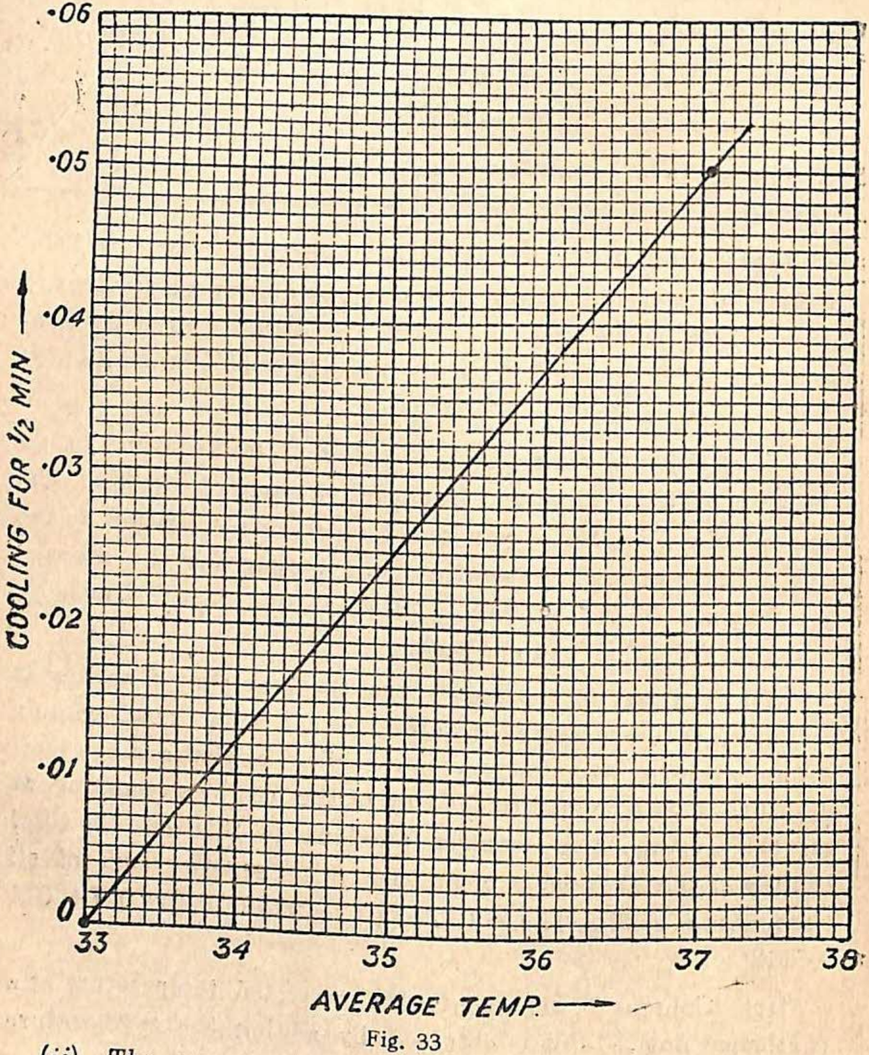

Fig. 33

(*ii*) The average temperature in °*C.* is plotted along the *x*-axis while cooling for ½ min. is plotted along the *y*-axis (Fig. 33). Plotting the two given points [obtained in item (*i*)] a straight line is drawn by joining these two points. From this straight line curve cooling for 1/2 min. (the value of the ordinate) for any definite average temperature (the value of the abscissa) is found out and put in the column 4 in Table III.

(F) *To find correct temperature* (*T*) :—

The correct temperature *T* can be obtained from the column 7 of table III. The best way to find *T* is to draw a curve by plotting time in minutes along *x*-axis and average temperature (both uncorrected and corrected) along *y*-axis. The upper part of the curve connecting time and uncorrected average temperature will bend towards the time axis while the upper part of the curve connecting time and corrected temperature will be horizontal (Fig. 34). The ordinate of this horizontal part will be the correct temperature *T*.

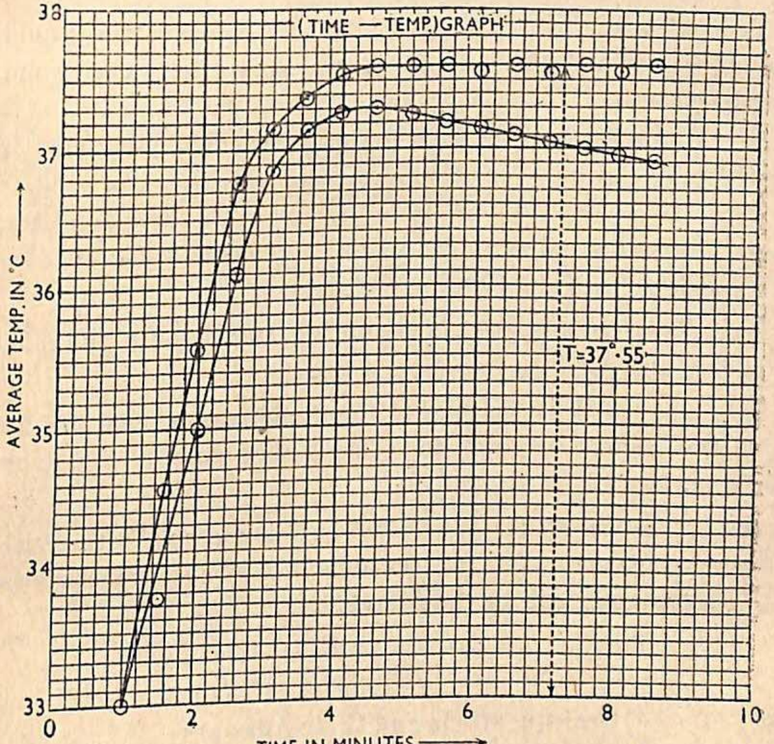

Fig. 34

Calculations :

Taking the corrected temperature T, either from the column 7 of table III, or from the graph of Fig. 34 we may calculate the sp. heat of liquid (or of solid) as follows :—

$$ms(t_2 - T) = (m_1 s_1 + m_2 s_2)(T - t_1)$$

$$20{\cdot}2 \times {\cdot}21(99 - 37{\cdot}55) = (108{\cdot}42 \times {\cdot}09 + 92{\cdot}07 \times s_2)(37{\cdot}55 - 33)$$

from which we get, $s_2 = {\cdot}516$ cal. per gm. per °C.

The liquid taken here is paraffin oil whose correct sp. heat is ·53 cal. per gm. per °C. [when s is to be found out, put the value of s_2 in the above formula and calculate s].

Precautions : (*i*) The quantity of calorimetric liquid should be just sufficient to cover completely the solid introduced in it.

(*ii*) While heating, the solid is kept suspended by the side of the thermometer bulb for getting correct temperature of solid.

(*iii*) To ensure uniformity of temperature throughout the solid, the reading (t_2) as shown by the thermometer T_2, is to be kept steady *for at least* 10 minutes.

(*iv*) To avoid any loss of heat during transference, the solid is quickly dropped into the calorimetric liquid.

(*v*) The solid is dropped in the liquid from a small height above the liquid surface, to prevent the loss of liquid by splashing.

(*vi*) The *size of the solid should not be too small* otherwise the percentage error due to loss of heat during its transference to the calorimeter will be considerable.

Oral Questions and their Answers

1. Define Calorie and British Thermal Unit (B. Th. U.).

Calorie is the quantity of heat required to raise 1 gm. of water from 14½°C. to 15½°C.

British Thermal Unit is the quantity of heat required to raise the temperature of 1 lb. of water by 1°F and it is equal to 252 cals.

2. Define sp. heat, thermal capacity and water equivalent. What ar their units ?

Sp. heat of a substance is the quantity of heat required to raise the temperature of unit mass of the substance by 1°C. Its unit is, *calorie per gm. per °C.*

Thermal capacity of a body is the quantity of heat required to raise the temperature of the body by 1°C. Thus thermal capacity of a body of mass m and sp. heat s is ms *calories.*

Water equivalent of a body is the number of gms. of water which will be raised by 1°C. by the quantity of heat required to raise the temperature of the body by, 1°C, Thus water equivalent of a body of mass m and sp. heat s is ms *gms.*

3. What is the harm, if very small or large quantity of liquid are taken in the calorimeter ?

In the former case, part of the solid will be outside the liquid and hence a part of its heat will be transferred to the outside air also. In the latter case, the rise of temperature of the liquid will be very small by which correct value of specific heat cannot be obtained

4. State the law which you assume here in correcting for the loss of heat by radiation.

Newton's law of cooling which is assumed here, states that the rate at which a hot body cools is proportional to the difference of temperature between the hot body and the surroundings.

5. Is the law true for any difference of temperature ?

The law is true only when the difference of temperature between the hot body and the surroundings is small.

6. What factors influence the radiation of heat from a hot body ?

(i) Extent and nature of the radiating surface ; (ii) Difference of temperature between the hot body and its surroundings.

7. In determining the specific heat of a solid what liquid you would prefer as calorimetric liquid ?

Usually a liquid of low sp. heat is preferred, for in that case rise of temperature will be greater ; whereas in the case of water, rise of temperature will be less due to the high specific heat of water.

8. Why do you heat the solid in hot air ?

If the solid be heated by introducing it into steam or hot water, then the calorimetric liquid will get heat not only from the hot solid but also from the hot water on the solid.

9. Would you prefer a lump solid or a solid in the form of pieces ?

If the solid be a conductor then the lump solid will not be harmful for the temperature throughout the mass may be same. If the solid be a bad conductor then it is preferable to have the solid in the form of pieces so that the temperature of every piece may be the same.

10. Why do you prefer a solid of appreciable size for your experiment ?

Heat contained in the body will be proportional to the volume of the body while heat lost by the body during transference is proportional to its surface area. Since the increase in volume is more rapid than the increase in surface, the loss of heat decreases as the volume of the body becomes greater.

11. Why do you make an elaborate arrangement like this ?

This is just to be sure that the heat lost by the hot solid wholly goes to the calorimeter and its contents.

32. *Determination of the latent heat of fusion of ice, by employing radiation correction.*

Apparatus : The apparatus required for this purpose is simply a calorimeter of the type as shown in Fig. 32.

[For description—see item (*ii*) of 'apparatus' in Expt. 31.]

Theory : The latent heat (L) of fusion of ice is defined as the quantity of heat required to convert unit mass of ice at $0°C$. to water at $0°C$. Let,

m_1 and s_1 = mass and sp. heat of calorimeter and stirrer respectively ;

t_1 and t = initial and final observed temperatures of calorimetric water respectively ;

m_2 = mass of calorimetric water ;

M = mass of ice (at $0°C$.) added.

Heat gained by ice in melting and for its rise of temperature to $t°C. = ML + Mt$.

Heat lost by calorimeter and its contents in cooling from $t_1°C$. to $t°C. = (m_1s_1 + m_2)(t_1 - t)$.

If there be no gain of heat from the surroundings then,

$$M(L+t) = (m_1s_1 + m_2)(t_1 - t) \quad \ldots \quad \ldots \quad (1)$$

The lowest observed temperature (t) of the mixture is usually greater than the actual value T, due to the gain of heat from the surroundings by radiation. If the value of T be found out from the observed data then the corrected relation is,

$$M(L+T) = (m_1s_1 + m_2)(t_1 - T)$$

$$\text{or,} \quad L = \frac{(m_1s_1 + m_2)(t_1 - T)}{M} - T \quad \ldots \quad \ldots \quad (2)$$

The relation (2) is employed to determine the latent heat of fusion of ice.

Procedure : (*i*) At the beginning, the dew point of air at the time of experiment should be known so that the final lowest temperature of the mixture may remain at least 5°*C*. above the dew point.

(*ii*) The mass (m_1) of dry, clean and empty calorimeter and stirrer is determined and then the mass (m_1+m_2) of calorimeter, stirrer and water in it (filling about $\frac{2}{3}$ of calorimeter) is determined. From the two masses, the mass m_2 of water taken is found out. The calorimeter is then replaced in its position in the copper vessel *V*.

(*iii*) A thermometer reading $\frac{1}{10}$°*C*. is introduced in the calorimetric water and its initial temperature (t_1°*C*.) is noted successively for three intervals of time at an interval of $\frac{1}{2}$ minute.

(*iv*) Clear ice is broken into pieces of convenient sizes and these pieces are dropped one by one in the calorimetric water, after soaking all waters on the outer surface of each piece by dry and fresh blotting papers. The dropping of ice-pieces should be continued until the lowest temperature of mixture is above the dew point by about 5°*C*. After dropping each piece of ice, the water is stirred vigorously and ice is not allowed to float on the water surface.

(*v*) The temperature of the mixture is noted after an interval of $\frac{1}{2}$ minute, beginning from at least 3 consecutive intervals before the introduction of ice and ending when eight rising temperatures, after the attainment of lowest temperature (t°*C*.), are noted.

(*vi*) After this, the calorimeter with its contents is allowed to come at room temperature. Now the mass (m_1+m_2+M) of calorimeter and stirrer with water and molten ice in it, is determined by a balance. From this, the mass *M* of ice added is found out.

(*vii*) From these observed data, the rise of temperature of the calorimeter and its contents by an amount of x°*C*., due to the gain of heat by radiation from the surroundings, during the course of its attainment of lowest temperature t°*C*. is calculated and the corrected common temperature then becomes $T=(t-x)$°*C*.

Experimental data :

(A) *Recording of weights and other constants :—*

TABLE I

Masses of,					Sp. heat of calor, and stirrer
(*a*) Calorimeter +stirrer m_1	(*b*) Calorimeter +stirrer+ water (m_1+m_2)	$(b)-(a)$ Water taken (m_2)	(*c*) Calor.+ stirrer+ water+ice $(m_1+m_2)+M)$	$(c)-(b)$ ce added M	s_1
...gm+.. gm +....mg+... =.. gm.	...gm+...gm +...mg+... =...gm.	(...)−(...) =...gm	... gm+.. gm + mg+.. =...gm	(...)−(...) =...gms.	·09

(B) *Time-temperature record.*

TABLE II

Initial temperature of water $= t_1\,°C. = \cdots °C.$

Dew point of air (supplied) $= \cdots °C.$

1 Time in minutes	2 Temp. of calorimeter in °C. (*θ*)	3 Average temp. in °C (*θ′*)	4 Heating during the interval from radiation curve in °C	5 Total heating at the end of interval in °C. (*y*)	6 Corrected temperature in °C. $(\theta-y)$	7 Corrected temperature of the mixture $=T$°C.
Room temp. 0	...(t_1)					
½	...(,,)					
1	...(,,					
Falling Temps.	Ice dropped					
1½	...	...	...	...	...	
2	...	...	...	...	...	...
etc.	etc.	etc.	etc.	etc.	etc.	
Rising Temp. ...	...	...	...	...	...	
...	...	...	...	...	...	
...	...	...	...	...	...	
...	...	...	...	....	...	
...	....	...	...	....	...	
...	....	...	...	...	...	
...	...	...	...	...	...	
...	...	...	...	..	.	

(C) *To find the rate of heating from Table II :—*

TABLE III (c. f. TABLE II of Expt. 31)

Interval of two minutes.	Rise of temp. in °C	Heating for 2 mins. in °C.	Average heating for ½ min. in °C.	Average of eight rising temps. of Table II
from ...to ... min.	from . to...	...	...	---
,, ...to... ,,	,, ...to...	...		
,, ...to .. ,,	,, ...to ..	---		
,, ...to .. ,,	,, .. to...	...		

(D) *To draw the radiation curve :—*

(*i*) The rise of temperature for ½ min. at the average of eight rising temperatures is obtained from Table III. The rate of heating at room temperature (t_1°C.) is zero. Thus the two points for the curve are found out.

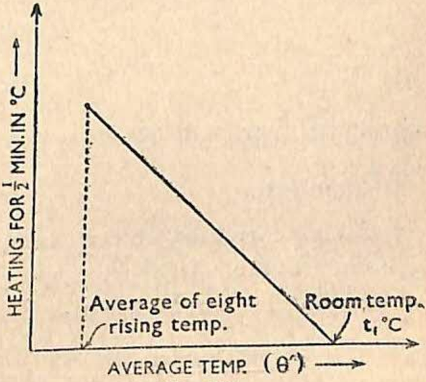

Fig. 35

(*ii*) The average temperature (θ') is plotted along x-axis while the corresponding heating for half minute is plotted along y-axis. The two points obtained in item (*i*) are plotted and joined by a straight line. The nature of this curve will be as shown in Fig. 35. From this straight line curve, heating for ½ min. (ordinate) for any definite average temperature (abscissa) is found out and put in the column 4 of Table II.

(E) *To find corrected lowest temp* (T) :—

The corrected lowest temperature T can be obtained from column 7 of Table II. The best way to find T is to draw a curve by plotting time in minutes along x-axis, and average temperature (both uncorrected and corrected) along y-axis. The lower part of the curve, connecting time and uncorrected temperature, will bend upward, while the lower part of the curve, connecting time and corrected temperature will be horizontal and parallel to the time axis (Fig. 36). The ordinate of this horizontal part will be the corrected lowest temperature T.

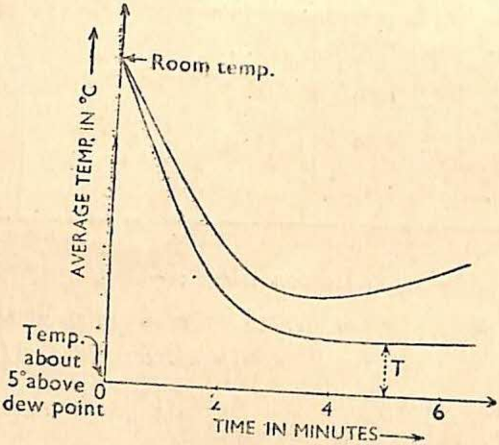

Fig. 36

Calculation :

Taking corrected lowest temperature (T) either from the column 7 of table II or from the graph of Fig 36, the latent heat of fusion of ice can be calculated as follows :—

$$L = \frac{(m_1 s_1 + m_2)(t_1 - T)}{M} - T,$$

or, $L =$ ... ...

or, $L =$ ... ...calories per gm.

Precautions : (*i*) The ice added should be made dry by soaking any water on its outer surface with a fresh blotting paper.

(*ii*) The ice is to be kept under water during stirring ; otherwise heat will be taken from outside, for melting.

(*iii*) The lowest temperature is not allowed to go below dew point ; otherwise heat of condensation will be given to the calorimeter.

(*iv*) Splashing of water during the dropping of ice is to be avoided.

(*v*) The ice added must be pure ; otherwise impurities in it will not contribute anything towards latent heat of ice.

Oral Questions and their Answers

1. Define latent heat and latent heat of fusion of ice.

Latent heat of a substance is the quantity of heat required to change the state of unit mass of the substance without any change of temperature. Its unit in c g.s. system is calories per gm. [For def. of latent heat of fusion of ice—see Theory].

2. Why is dry ice necessary ?—If the ice carries some water with it, then heat required for getting that water from ice is taken from the outside and not from the calorimeter and its contents. Hence the increase of weight after the addition of ice is not due to ice alone.

3, 4, 5.—[See answers to oral questions 4, 5 and 6 of Expt. 31].

6. Is the latent heat of substance same at all temperatures ?—By the application of pressure on the surface of the substance, it can be made to change its state at different temperatures and the latent heat required at different temperatures is not the same. Latent heat vanishes at the critical temperature of the substance.

7. Is there any relationship between latent heat and surface tension ? Yes ; both decrease with the increase of temperature and at critical temperature both disappear.

8. Why is the heat required for the change of state called latent ?

During this change of state, some heat is required which does not change the temperature of the substance. This heat simply increases the potential energy between the molecules. That is why it is called latent heat. The sensible heat, which raises the temperature of a substance, increases the kinetic energy of molecules.

33. Determination of the latent heat of condensation of steam.

Apparatus : The arrangement of apparatus is shown in Fig 37. The boiler (*B*) is about half-filled with water, by boiling which steam can be generated. This steam is led by a tube T_1 to a steam-trap which is nothing but a short cylinder whose two open ends are closed by rubber corks (R_1 and R_2). Through the lower cork (R_2) of the steam trap pass two tubes T_2 and T_3. The upper end of T_2 is bent downwards a little, while its lower end dips into water taken in the calorimeter (C), so that only the dry steam (i.e. uncondensed steam) can enter into the water. The tube (T_3) is provided with a pinch cock (K), by opening which condensed steam on the top of the cork (R_2) can be allowed to escape outside.

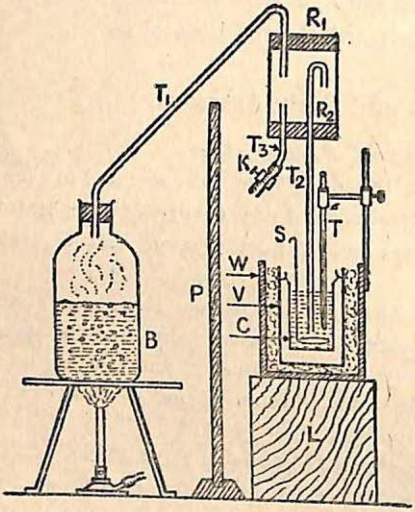

Fig. 37

The calorimeter C (whose outside is highly polished) is kept suspended inside another copper vessel V, the inside of which is kept highly polished to avoid loss of heat by radiation. The copper vessel V is again kept inside a wooden vessel W and the space between the wooden and copper vessels is packed with cotton wool. A stirrer S and a thermometer T are also introduced into the water of the calorimeter. There is a wooden partition P which prevents the transference of heat from the burner to the calorimeter.

Theory : Let M gms. of steam at t_2°C (boiling point of water which for all practical purposes may be taken as 100°C) be allowed to condense in m gms. of water at room-temperature t_1°C contained in a copper calorimeter of mass m_1 and sp. heat s_1. If the final temperature of the mixture, after applying correction for the loss of heat by radiation, be t°C, then,

Heat lost by steam $= ML + M(t_2 - t)$, where L is the latent heat of condensation of steam, which is the heat given up by the condensation of unit mass (one gm.) of steam at t_2°C (boiling point of water) to the same mass of water at the same temperature. Again, heat gained by calorimeter and its water $=(m+m_1s_1)(t-t_1)$. Assuming no loss or gain of heat,

$$ML+M(t_2-t)=(m+m_1s_1)(t-t_1)$$

$$\text{or,}\quad L=\frac{m+m_1s_1}{M}(t-t_1)-(t_2-t) \quad \cdots \quad \cdots \quad (1)$$

The relation (1) may be employed to find the latent heat of condensation of steam.

Radiation correction.—Let the steam be passed inside the calorimetric water for T' seconds, during which its temperature rises from t_1°C (room-temp.) to some other higher temperature θ_1 (say). Again let T_0 be the total time (counted from the instant at which steam is passed in water) required to raise the temperature of calorimetric water from t_1°C to the highest temperature θ_2°C. (θ_2 is slightly greater than θ_1). If x°C be the fall of temperature of water during the time $(T_0/2)$ counted from the instant (T_0) at which water assumes its highest temperature θ_2°C the corrected highest temperature is $t=(\theta_2+x)$°C. [For proof, see foot note of Expt. 48, Part II].

Procedure : (*i*) By filling nearly half of the boiler with water, two burners are applied below the boiler to form steam from water. This time the wooden vessel W with the vessel V and calorimeter C in it is removed to a distant place.

(*ii*) The calorimeter C is cleaned by a cotton pad and the mass m_1 of calorimeter and stirrer is determined when the calorimeter is empty. Two-thirds of the calorimeter is then filled with water and again the mass $(m+m_1)$ of the two is determined. Thus we get the mass m of water taken in the calorimeter. The temperature t_1°C of this water is noted by the thermometer T.

(*iii*) When steam is seen to escape briskly through the open end of the tube T_2, the calorimeter with its accessories are placed on the wooden block (L), so that the end of the tube T_2 may dip inside the water in the calorimeter. Simultaneously a stop-clock is started. Steam is passed and water is stirred by the stirrer S until the temperature of the water rises by about 20°C. This rise takes place within a short time (say, about a minute).

(*iv*) The calorimeter and all its accessories are now removed and the time T', at which supply of steam is cut off, is noted from the stop-clock and at the same time the temperature θ_1°C of water is noted. The water is stirred well and its maximum temperature θ_2 and the time T_0, at which this maximum temperature is attained are noted from the running stop-clock (which is allowed to run after its start).

(*v*) The water is continually stirred and its temperature is again noted at time $(T_0 + T_0/2)$. Let this temperature ot water be θ_3°C. Then corrected highest temperature of water $= t = (\theta_2 + x)$°C. where $x = (\theta_2 - \theta_3)$ and this represents the fall of temperature during the time $T_0/2$.

(*vi*) When the calorimeter and its contents come at room-temperature, they are again weighed. This time we get the mass (m_1) of calorimeter together with the mass (m) of water and the mass (M) of condensed steam. Thus the difference between this weight and the second weight $(= m + m_1)$ of calorimeter and water in it gives the mass (M) of steam condensed.

Experimental data :

(A) *Recording of masses and other constants :—*

TABLE I

Masses of					Sp. heat of cal. and stirrer
Cal. + stirrer (m_1)	Cal. + stirrer + water $(m_1 + m)$	Water taken (m)	Cal. + stirrer + water + condensed steam $(m_1 + m + M)$	Condensed steam (M)	(s_1)
.. gm + .. gm + ...mg + .. = ...gm.	.. gm + . gm + ...mg + ... = .. gm	(...) − (...) = .. gm.	gm + .. gm + ...mg + .. = .. gm.	(...) − (...) = .. gm.	...

(B) *Time-Temperature record* :—

TABLE II

Time	Temperature of water in °C	Correction due to radiation $=x=(\theta_2-\theta_3)$ in °C	Corrected highest temp. of water in °C $=t=(\theta_2+x)$
0 (steam not passed)	.. $(=t_1=$ room temp.)		
...min sec $(=T'$, when steam is cut off)	...$(=\theta_1)$		
...min...sec $(=T_0$ when temp. is max.)	...$(=\theta_2=$ max. temp.)	...	...
...min...sec. $(T_0+T_0/2)$	.. $(=\theta_3)$		

Calculation :

$$L=\frac{m+m_1s_1}{M}(t-t_1)-(t_2-t)= \quad \cdots \quad = \quad \cdots \text{ cals./gm.}$$

[t_2 may be taken as 100°C].

Discussions : (*i*) The rise of temperature is very rapid and the rise of temperature of about 20°C requires the passage of steam for a minute or so and hence the radiation loss is small. Thus the elaborate method of correcting for the radiation loss, as in the case of sp. heat experiment, is not profitable.

(*ii*) The rise of temperature of calorimetric water should not be made by more than 30°C. ; otherwise Newton's law of cooling will not hold good.

(*iii*) Perfectly dry steam cannot be passed within water. Hence the heat required for the condensed steam which enters into water is taken from outside and not from calorimetric water.

(*iv*) The temperature of steam (t_2°C) may be taken as 100°C. for due to the uncertainty in the experiment the error would not be appreciable.

Oral Questions and their Answers

1. What do you mean by the term 'latent heat of condensation of steam'? What is its unit?—For 1st part see theory. Its unit in c.g.s. system is calories per gm.

2. Is the latent heat of condensation of steam same at all temperatures?—No ; letent heat decreases as the boiling point of liquid increases. At a certain temperature, known as critical temperature, latent heat of vaporisation vanishes.

3. What do you mean by the term 'total heat' of saturated vapour?—The total heat of the saturated vapour of a liquid at a temperature t°C is the quantity of heat required to raise 1 gm. of the liquid from 0°C to t C and to convert it to saturated vapour at t°C.

4. What is the magnitude of total heat of steam at t°C ?

The magnitude of total heat of steam at t°C is given by, $Q = L_t + t$. Regnault found that the total heat of steam at t°C is $Q = 606{\cdot}5 + {\cdot}305t$. Thus we get $L_t = 606{\cdot}5 + {\cdot}305t - t$; or, $L_t = 606{\cdot}5 - {\cdot}695t$. This shows that L_t disappears at 872°C.

5. What is Trouton's rule?—Molecular latent heat of a liquid at its boiling point T_b (absolute temperature) is the product of the molecular weight (M) of the liquid and its latent heat (L) at absolute temperature T_b. The ratio of (ML) and T_b is constant, *i.e.*, ML/T_b = constant which is known as Trouton's rule. This constant is about 20 for many substances.

6. What do you mean by internal and external latent heats?—When a unit mass of a liquid changes to vapour, a large change of volume occurs. Heat required for doing external work due to the increase in volume is called *external latent heat*, while the heat required for the change of liquid to vapour minus the heat required for external work will be the *internal latent heat*.

34. To determine the specific heat of a liquid by the method of cooling.

Apparatus : It consists of a copper calorimeter C provided with a lid L having two holes in it [Fig. 38]. A thermometer T can be tightly inserted in the central hole of the lid and if necessary, a rotary type of stirrer S may be introduced in the liquid whose stem can project out of the lid through its side hole. The outside of the calorimeter is painted dead black and is kept suspended by three strings inside a double-walled metal vessel *J*. The annular space between the double walls may be filled with water or air at room-temperature to ensure a fixed surrounding for the calorimeter.

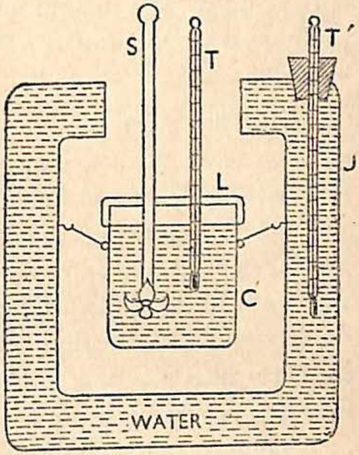

Fig. 38

Theory : The quantity of heat lost per second by a hot body in a given surrounding depends (*i*) on the temperature of the body and (*ii*) on the nature and area of the exposed surface of the body.

If a hot liquid of mass m_1 and sp. heat s_1 fills about three quarters of a calorimeter of mass m and sp. heat s and requires t_1 seconds to cool from $\theta_1{}^\circ C$ to $\theta_2{}^\circ C$, the average loss of heat per second is,

$$\frac{(ms+m_1s_1)(\theta_1-\theta_2)}{t_1} \text{ calories.} \quad \ldots \quad \ldots \quad (1)$$

If hot water of mass m_2 and of the *same volume* as the liquid. fills the same length of the former calorimeter and requires t_2 seconds to cool through the same range of temperature (*viz.*, from $\theta_1{}^\circ C$ to $\theta_2{}^\circ C$) in the same surroundings as before then the average loss of heat per second is,

$$\frac{(ms+m_2)(\theta_1-\theta_2)}{t_2} \text{ calories.} \quad \ldots \quad \ldots \quad (2)$$

As the rate of loss of heat is independent of the nature of liquid, we may equate the relations (1) and (2). Hence we get,

$$\frac{(ms+m_1s_1)}{t_1}=\frac{ms+m_2}{t_2}$$

$$\text{or,} \quad s_1=\frac{1}{m_1}\left\{\frac{t_1}{t_2}(ms+m_2)-ms\right\} \quad \ldots \quad \ldots \quad (3)$$

The sp. heat s_1 of liquid can be found out from (3).

Procedure : (*i*) The mass (m) of empty calorimeter and stirrer only (and *not* of the lid) is determined and a mark is made on its inner wall at a place which is about 2 or 3 cms. below the top.

(*ii*) The given liquid is heated to about 70°C in a beaker and poured in the calorimeter up to the mark. A thermometer is fitted to the central hole of the lid in such a way that when the lid is placed at the mouth of the calorimeter, the bulb of the thermometer may remain at the centre of the calorimeter while the stem of the stirrer may come outside the lid through its side-hole. The calorimeter is then kept suspended in the double-walled chamber. If necessary, the liquid may be stirred by a rotary stirrer and its temperature is noted after an interval of 1 minute until the temperature falls to near about 40°C.

(*iii*) The calorimeter with its lid and liquid is brought outside and is cooled to about room-temperature. This time the mass ($m+m_1$) of the calorimeter, stirrer and liquid in it (but *not* of the lid) is determined, from which the mass m_1 of the liquid taken is found out.

(*iv*) The liquid is now poured out of the calorimeter and any liquid sticking on its inner surface is wiped out by a clean cloth. The outside of the calorimeter is not touched more than is absolutely necessary.

(*v*) The procedure followed in (*ii*) is repeated in a similar manner by taking hot water in the calorimeter *up to the same mark as before* (i.e. the volumes of water and liquid must be equal). When the water cools to about 40°C, the calorimeter with its lid and water is brought outside and cooled to about room-temperature. The mass ($m+m_2$) of the calorimeter, stirrer and water in it (and *not* of the lid) is determined from which the mass m_2 of the water taken is found out.

(*vi*) Two cooling curves are now drawn with the time (t) in minutes as abscissa and the temperature (θ) as ordinate [Fig. 38(a)]. From these two curves the times t_1 and t_2 required by the liquid and water respectively to cool from θ_1°C

to $\theta_2{}^\circ C$ are found out. On putting the observed data in equation (3) the sp. heat s_1 of the given liquid can be calculated.

Experimental data :

(A) *Recording of weights and other constants :—*

TABLE I

Masses of,					Sp. heat of calorimeter and stirrer (s)
(a) Calorimeter + stirrer (m)	(b) Calorimeter + stirrer + V vol of liquid $(m+m_1)$	$(b)-(a)$ Liquid taken (m_1)	(c) Calorimeter + stirrer + V vol. of water $(m+m_2)$	$(c)-(a)$ Water taken (m_2)	
...gm + gm +...mg+... =...gm.	...gm + .. gm +...mg+... = .. gm.	(...)−(...) =.. gms.	. gm + .. gm +...mg+... =.. gm.	(...)−(...) =gm.	...

(B) *Time-temperature record :—*

TABLE II

Time in minutes→	0	1	2	3	4	5	6	7	etc.
Temperature of liquid in °C→	...	...	...	...	...	....	...	...	etc.
Temperature of water in °C→	...	...	...	...	....	...	....	...	etc.

(C) *Drawing of cooling curves :—*

Time (t) in minutes is plotted along the x-axis having the origin as zero, while the temperature (θ) is plotted along the y-axis having the value of the origin a temperature, which is a few degrees lower than the lowest temperature noted. Points for both liquid and water are plotted on the same graph paper and in each case the points are joined by smooth curves. Thus two cooling curves are drawn, the nature of which are shown in Fig. 38(*a*). Two straight lines are drawn parallel to the time-

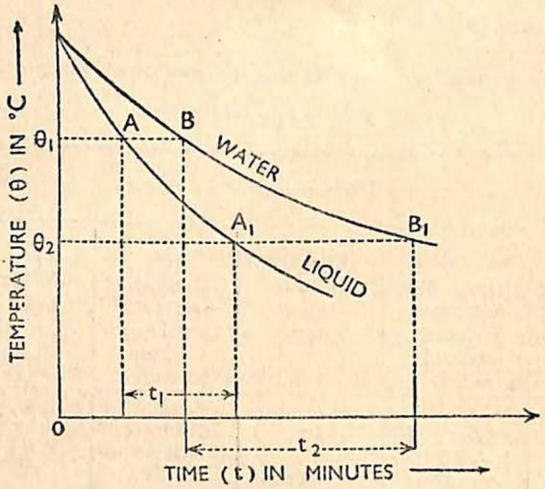

Fig. 38(*a*)

axis from θ_1° and θ_2°, so that $(\theta_1-\theta_2)$ is not less than $20^\circ C$ Let the straight line from θ_1° cut the cooling curves for liquid and water at A and B respectively, while that from θ_2° cuts those two curves at A_1 and B_1 respectively. Lengths of the abscissa t_1 and t_2 corresponding to points (A, A_1) and (B, B_1) of the cooling curves for liquid and water respectively are found out from the graph. Thus we get, time required by liquid to cool from . $^\circ C\ (\theta_1)$ to .. $^\circ C\ (\theta_2)$ is $= t_1 =$ .. secs.

Time required by water to cool through the same range of temperature $= t_2 =$ ......secs.

Calculation :

The formula employed is $s_1=\frac{1}{m_1}\left\{\frac{t_1}{t_2}(ms+m_2)-ms\right\}$

Putting the data obtained in (*A*) and (*C*), we get

$s_1=$ ... $=$ ... cals. per gm. per °C.

Precautions : (*i*) The liquid employed should be heated outside and not in the calorimeter itself.

(*ii*) To avoid evaporation of liquid, the lid should be fitted tightly and, *if necessary*, a rotary stirrer should be employed, for an up-and-down stirrer would promote evaporation. The calorimeter should be almost filled with the liquid and the initial temperature of the liquid should not be near about its boiling point.

(*iii*) The temperature of the outside of the calorimeter is assumed to be the same as that of the liquid. For this to happen, the calorimeter should be made very thin and cylindrical in form with a length about three times its diameter.

(*iv*) To get a fixed surrounding, the calorimeter should be kept suspended in a double-walled chamber containing water in their annular space.

Oral Questions and their Answers

1. What is the law which you assume here for finding the sp. heat of liquid ? [See the answer of oral Q. 4. Expt. 31].

2 & 3—[Same as oral Qs. 5 and 6 of Expt. 31]

4. Why is the outside of the calorimeter painted black ?

To make it a good radiator.

5. Is it necessary to employ the lid of the calorimeter ?—Yes ; otherwise evaporation will increase, causing a decrease of the mass of liquid.

6. Why are the same volume of water and liquid employed ?

By this the surface area, from which radiation occurs, is kept equal in both cases.

7. Can you find the sp. heat of a very volatile liquid by this method ?

If the liquid is very volatile, its boiling point remains not far away from the room temperature. Hence the observation of cooling from a temperature, which is at least 30°C higher than room temperature would not be possible.

35. *Determination of the thermal conductivity of a metal by Searle's apparatus.*

Apparatus : The apparatus employed is shown in Fig. 39. It consists of a metal rod *AB* of about 3 cm. in diameter and 20 cm. in length. A chamber *C* is fixed at the end *A* of the rod in which steam can be passsd to heat the rod. A spiral tube S of copper is wound over the other end B of the rod, in which cold water can be made to circulate.

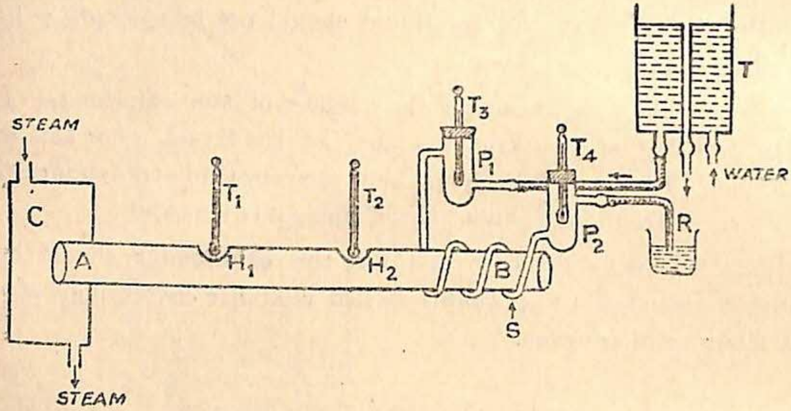

Fig. 39

Two thermometers T_3 and T_4 [reading $(1/10)°C$] are introduced in the pockets P_1 and P_2 to record the temperatures of the in-coming and out-going waters respectively. The water enters the spiral tube S from a constant level water-tank T. Two other thermometers T_1 and T_2 (reading $\frac{1}{2}°C$) are introduced into the mercury contained in the two holes H_1 and H_2 drilled on the rod at a distance of about 7 cm. apart. The whole apparatus is covered by felt to prevent the loss of heat.

Theory : Let a steady gradient of temperature be maintained in a highly conducting rod of sectional area A by constantly circulating steam at one end and room-temperature water at the other end. If θ_1 and θ_2 be the steady temperatures at the two sections of the rod (so that $\theta_1 > \theta_2$) separated by a distance l, the heat conducted through the cold section at θ_2 in time t seconds is given by

$$Q = \frac{KA(\theta_1 - \theta_2)\,t}{l} \quad \cdots \quad \cdots \quad (1)$$

Here K is the coefficient of thermal conductivity of the material of the rod. If this conducted heat (Q) is exclusively supplied (assuming no loss of heat by radiation) to m gms. of the circulating water flowing out in t seconds, having its temperature raised from θ_3 to θ_4, then

$$Q=m\ (\theta_4-\theta_3) \quad \ldots \quad \ldots \quad (2)$$

From (1) and (2) we get

$$\frac{KA(\theta_1-\theta_2)\ t}{l}=m\ (\theta_4-\theta_3),$$

$$\text{or,}\quad K=\frac{l}{A}\times\frac{m}{t}\times\frac{\theta_4-\theta_3}{\theta_1-\theta_2} \quad \ldots \quad \ldots \quad (3)$$

If the initial readings of the four thermometers at room-temperature are the same, the highest steady temperatures θ_1, θ_2, θ_3 and θ_4 indicated by thermometers T_1, T_2, T_3 and T_4 should be put in the equation (3) to calculate K. But if the initial readings of the four thermometers are respectively t_1, t_2, t_3 and t_4 (which is usually the case) the corrections $x=(t_2-t_1)$ and $y=(t_3-t_4)$ should be found out which should respectively be added algebraically to the observed values of $(\theta_1-\theta_2)$ and $(\theta_4-\theta_3)$, so that their correct values may be obtained.

Procedure : (*i*) About two-thirds of the boiler is filled with water and one or two burners are applied below to produce steam.

(*ii*) If the rod is uniform in cross-section and a portion of it is exposed outside, its diameter d should be measured at several places of the exposed portion by a slide callipers and the mean value of d is found out, from which the cross-section (A) of the rod is calculated from the relation $A=\pi d^2/4$. If the diameter of the rod cannot be measured (which is usually the case), its value should be supplied.

(*iii*) The distance l between the centres of the thermometers T_1 and T_2 should be measured by a scale. Usually this distance is also supplied.

(*iv*) The bulbs of the four thermometers T_1, T_2, T_3 and T_4 are placed in their respective positions. Thermometers T_1

and T_2 should read $(1/2)^\circ C$, while the thermometers T_3 and T_4 should read $(1/10)^\circ C$. Before the passage of steam in the chamber C the initial errors of the thermometers (if any) should be found out. For this purpose the readings of the four thermometers are noted for 6 minutes at intervals of two minutes. At this time, the thermometers will record steady temperatures. If t_1, t_2, t_3 and t_4 are respectively the readings of T_1, T_2, T_3 and T_4, the corrections, which will have to be added algebraically to the final values of $(\theta_1 - \theta_2)$ and $(\theta_4 - \theta_3)$ are respectively $x = (t_2 - t_1)$ and $y = (t_3 - t_4)$.

(*v*) During the operation (*iv*), steam will be ready. The rubber tubes carrying steam from the boiler is now joined to the chamber C, while cold water from a constant-head water tank T is made to circulate in the spiral tube at the other end. By adjusting the screw-cap (not shown in Fig. 39) on the rubber tube R attached to the outlet tube of cold water the flow of water is so regulated that the temperature difference $(\theta_4 - \theta_3)$ is nearly $8^\circ C$.

(*vi*) When $(\theta_4 - \theta_3)$ is approximately steady, temperatures recorded by four thermometers are noted at intervals of 2 minutes until they are steady for at least three consecutive intervals. If these steady temperatures shown by T_1, T_2, T_3 and T_4 are respectively t'_1, t'_2, t'_3 and t'_4, corrected $(\theta_1 - \theta_2)$ would be $(t'_1 - t'_2) + x$ while corrected $(\theta_4 - \theta_3)$ would be $(t'_4 - t'_3) + y$. At this steady state of temperatures, water from the outflow tube (which should not be disturbed during experiment) is collected in a beaker of known mass $= (w_1)$ for t seconds (noted by stop-clock) until about three-fourths of the beaker is full. The mass w_2 of beaker with this water in it is again determined, from which the mass $m = (w_2 - w_1)$ of water collected in t seconds is found out.

(*iii*) The experiment is repeated by regulating the flow of water, when the difference of temperature between the outgoing and incoming water, is maintained steady at about $10^\circ C$

and 12°C. K is calculated from each set of data by using the equation (3) and the mean value is found out.

Experimental data :

(A) *Diameter* (d) *of the rod* (if not supplied) :—

TABLE I

[Make a chart for slide callipers as in Expt. 10 and take at least 5 observations.]

(B) *Distance* (l) *between the thermometers*, T_1 and T_2 :—
[If not supplied]

$$l=\frac{(i)\cdots+(ii)\cdots+(iii)\cdots}{3}= \quad \cdots \quad \text{cm.}$$

(C) *To find initial errors of the thermometers* :—

TABLE II

Stage of expt.	Time in minutes	Initial readings in °C of thermometers.				Correction to be added algebraically to $(\theta_1-\theta_2)$ is, $x=(t_2-t_1)$	Correction to be added algebraically to $(\theta_4-\theta_3)$ is $y=(t_3-t_4)$
		T_1	T_2	T_3	T_4		
When no steam is passed in C	0	...	...	...	....	...	...
	2	,,	,,	,,	,,		
	4	,,	,,	,,	,,		
	6	... $=t_1$	... $=t_2$	... $=t_3$	.... $=t_4$		

(D) *Time-temperature record of thermometers* :—

TABLE III

Stage of expt.	Time in minutes	No. of obs.	Readings in °C of thermometers. T_1	T_2	T_3	T_4	Corrected value of $(\theta_1-\theta_2)$ in °C $=(t_1'-t_2')+x$	Corrected value of $(\theta_4-\theta_3)$ in °C $=(t_4'-t_3')+y$
When steam is passed in °C	0		...	...	...	...		
	2	I	...	...	...	...		
	:		etc.	etc	etc.	etc.	...	... (nearly 8°C)
	6		... $=t_1'$	.... $=t_2'$	.... $=t_3'$	... $=t_4'$		
	0		....	...	...	...		
	2	II	...	...	...	...	....	... (nearly 10°C)
	: 6		... $=t_1'$	... $=t_2'$	... $=t_3'$	... $=t_4'$		
	0		...	...	...	...		
	2	III	...	...	... ...	...	...	... (nearly 12°C)
	: 6		.... $=t_1'$	... $=t_2'$	... $=t_3'$	... $=t_4$		

(E) *To find the mass* (*m*) *of water collected in 't' seconds* :—

TABLE IV

No. of obs.	Mass of empty beaker (w_1)	Time of collection of water in secs. (t)	Mass of beaker + water collected in t secs. (w_2)	Mass of water in gms. collected in t secs. is $m=(w_2-w_1)$
1	... gm + ... gm + ... mg + ... mg + ... = ... gms.	... min ... secs. = ... secs.	.. gm + ... gm + ... mg + .. mg + ... = ... gms.	...
2	,,	...	...	...
3	,,	...	....	...

(F) *Determination of K :—*

TABLE V

$l=$ ...cms. ; $A=\pi d^2/4=\quad=$ ...sq. cm.

No. of obs.	Time of collection of water in secs (t)	Mass of water collected in gms. in t secs. (m)	Corrected value of $(\theta_1-\theta_2)$ in °C	Corrected value of $(\theta_4-\theta_3)$ in °C	Value of K in cals. per sec. per cm. per °C	Mean K in c.g.s. unit
1	...	...	....	....	...	
2	....	....	...	...	....	...
3	...	...	...	...	....	

Calculation :

Formula is, $K=\dfrac{l}{A}\cdot\dfrac{m}{t}\cdot\dfrac{\theta_4-\theta_3}{\theta_1-\theta_2}$

(*i*) $K=$ ... = cals. per sec. per cm. per °C.

(*ii*) $K=$ ... = ...

(*iii*) $K=$ ... = ...

Precautions : To ensure 'steady state' the temperatures indicated by the four thermometers should remain constant for at least three consecutive intervals, *i.e.* for 6 minutes.

(*ii*) For greater accuracy, $(\theta_1-\theta_2)$ and $(\theta_4-\theta_3)$ should be adjusted to be of the same order ; otherwise the error due to the greater exposed part of the stem of the thermometers outside the hot bath, may be considerable

(*iii*) If the readings of the four thermometers at room-temperature differ, then the corrections x and y, which should respectively be added algebraically to the observed values of $(\theta_1-\theta_2)$ and $(\theta_4-\theta_3)$, will have to be determined previously.

(*iv*) To maintain a steady flow of water, *no part of the out-flowing rubber tube should be displaced* during the time of collection of water.

(*v*) Time of collection of water should be such so as to fill about $\frac{3}{4}$ths of the beaker. By this, the error introduced in weighing would be minimum.

Oral Questions and their Answers

1. Define thermal conductivity. How does it differ from thermometric conductivity ?

Thermal conductivity (K) is defined as the quantity of heat which flows normally per sec. through the cold face of a unit cube when unit difference of temperature is maintained between the two opposite faces of the cube. Thermometric conductivity $= \frac{K}{\rho s}$; where ρ and s are respectively the density and sp. heat of the substance.

2. What are the unit and demension of thermal conductivity K ?

In c.g.s. system the unit of K is cals. per sec. per cm. per °C. The *thermal dimension* of K is $QL^{-1}\ T^{-1}\ \theta^{-1}$, while its dynamical dimension is $MLT^{-3}\theta^{-1}$. Here Q and θ represent the quantity of heat and temperature respectively.

3. What is the temperature gradient ?

It is the change of temperature per unit length and is equal to $(\theta_1 - \theta_2)/l$.

4. Does the value K depend on the dimension of the rod ?—No, it depends only on its material.

5. Why do you maintain the temperature difference $(\theta_4 - \theta_3)$ near about 10°C ?

The error due to the exposed column of thermometers would be minimum when $(\theta_4 - \theta_3)$ is of the same order as $(\theta_1 - \theta_2)$ which is near about 10°C ?

6. Is the method suitable for a bad conducting substance ?

No ; the method is suitable for good conductors only, for which the loss of heat by radiation from the surface is negligible.

7. Why constant-level water-tank is necessary for your experiment ?

Constant-level water-tank will maintain a constant height of water which will maintain a constant pressure-difference under which water is flowing. Hence the rate of flow of water will remain steady.

36. *Lee's method of determining the thermal conductivity of a badly conducting substance.*

Apparatus : The arrangement of the apparatus is shown in Fig. 40. C is a circular metal disc over which the badly conducting circular sheet S is placed. The sheet S is of uniform thickness and has the same surface area as that of C. A steam chamber A is placed on S. The bottom B of this steam chamber is a thick circular metal plate having the same surface area as that of S.

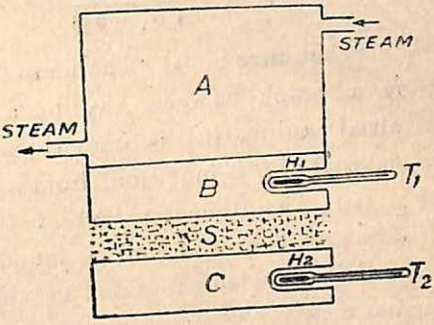

Fig. 40

To record the temperatures of B and C two holes H_1 and H_2 are respectively drilled in them to introduce thermometers T_1 and T_2. T_1 should read up to ·2°C while T_2 should read up to ·1°C. The whole apparatus is kept suspended by three chains from a support.

Theory : Let θ_1 = temperature of B in the steady state,

θ_2 = " " C " " " "

A = surface area of the badly conducting sheet S,

K = thermal conductivity of the sheet S

and d = thickness of the sheet S.

Quantity of heat conducted per second through the badly conducting sheet S is,

$$Q=\frac{KA(\theta_1-\theta_2)}{d} \quad \dots \quad \dots \quad (1)$$

In the steady state, this heat Q is radiated per second from the lower disc C. If m and s be respectively the mass and sp. heat of C and $d\theta/dt$ be its rate of cooling at its temperature θ_2, the heat radiated per second from C is

$$Q = ms\frac{d\theta}{dt}. \qquad \dots \qquad \dots \qquad \dots \qquad (2)$$

From (1) and (2) we get

$$K = \frac{ms\frac{d\theta}{dt}d}{A(\theta_1 - \theta_2)}. \qquad \dots \qquad \dots \qquad \dots \qquad (3)$$

Procedure : (*i*) The mass (m) of the disc C is determined by a rough balance, say by a spring balance, after noting its initial reading (if it is other than zero). The sp. heat s of the material of C is found out from a table.

(*ii*) The diameter ($2r$) of the sheet S is determined by a scale and its area $A = \pi r^2$ is found out.

(*iii*) The thickness d of the sheet S is measured by a microscope. The vernier constant of the microscope is first determined. A paper with a cross mark on it is attached to the upper slab B. When the sheet S is within the discs B and C, the microscope is focussed on the cross mark and the reading (R_1) of its scale and vernier is noted. The sheet S is then taken out and the same cross mark is again focussed by the microscope and the reading (R_2) of its scale and vernier is noted. The thickness (d) of the sheet S would then be obtained from, $d = R_1 \sim R_2$. This operation is repeated for three or four different points taken on B and the mean value of d is found out.

(*iv*) After determining the initial errors (if any) of the thermometers T_1 and T_2, steam is passed in A and the temperatures θ_1 and θ_2 of B and C respectively are noted at intervals of 5 minutes, until they remain steady for at least three consecutive intervals, *i.e.* for 15 minutes.

(*v*) The chamber A and the sheet S are then removed (the former being placed on a tripod stand kept on a wooden slab). The disc C is then heated uniformly by playing a burner on it until its temperature is 5° or 6° above the steady temperature of the disc *B*. The burner is then removed and when the upper and lower surfaces of *C* assume the same temperature, the sheet *S* is again placed on *C*. The fall of temperature of *C* is then noted at intervals of ½ minute until its temperature falls below θ_2 by about 10°*C*. A graph is then drawn with the time of cooling (t) as the abscissa and the temperature (θ) of *C* as the ordinate [Fig. 41]. A tangent is drawn to the curve at a point (*P*, say) of which the ordinate is θ_2. If this tangent makes an angle ϕ with the time-axis, then $\frac{d\theta}{dt}$ at θ_2 is given by,

$$\frac{d\theta}{dt}=\tan\ \phi=\frac{\text{value of the ordinate at the point } (P) \text{ of the curve}}{\text{intercept made by the tangent on time-axis}}$$

$$=PN/NL.$$

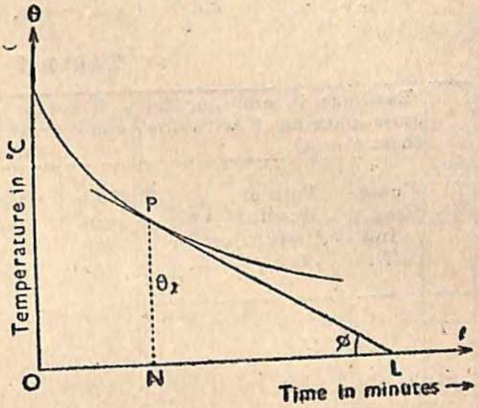

Fig. 41

Experimental data :

(A) (*i*) *Mass* (*m*) *of disc C* :—

Initial reading of the pointer of spring balance $=x_1=$ .. lbs.

Final " " " " " " " $=x_2=$ ...lbs.

Mass of the disc $C=m=(x_2-x_1)$ lbs. $=(x_2-x_1)\times 453{\cdot}6$ gms.

(*ii*) *Area* (*A*) *of the sheet S* :—

Diameter of the sheet $S=2r=\frac{\ldots+\ldots+\ldots}{3}=\ldots$cm.

Area of the sheet $S=A=\pi r^2=\ldots$sq. cm.

(*iii*) *Sp. heat of the disc* $C=s=\ldots$ (given).

(B) *To find the thickness (d) of the sheet (S) :—*

$$\ldots v.d. = \ldots s.d.,$$

or, $1\ v.d. = \ \ s.d.$

But, $1\ s.d. = \ldots mm.$

$\therefore \quad v.c. = (1\ s.d. - 1\ v.d.) = \ldots s.d. = \ldots cm.$

TABLE I

No. of obs.	Readings in cm. for the cross-mark on B with the sheet S on C.			Readings in cm. for the same cross-mark without the sheet S.			Thickness in cm. $= d = (R_1 \sim R_2)$	Mean d in cm.
	Scale Reading (S)	Vernier Reading $= V = (v.r.) \times (v.c.)$	Total Reading $= R_1 = S+V$	Scale reading (S)	Vernier Reading $= V = (v.r.) \times (v.c.)$	Total Reading $= R_2 = S+V$		
1								
2								
3								
4								

(C) *To find the initial errors of thermometers T_1 and T_2 :—*

TABLE II

Time in mins.	Initial reading in °C of thermometers.		Correction to be added algebraically to $(\theta_1 - \theta_2)$ is $x = (t_2 - t_1)$
	T_1	T_2	
0	....	....	
2	,,	,,	
4	,,	,,	...
6	... $= t_1$	.... $= t_2$	

(D) *Time-temperature records of B and C* :—

TABLE III (Room temp. = ... °C)

Time in minutes →	0	5	10	15	20	25	30
Temp. of B in °C →	....	...	....	....	....	...	... $=\theta_1$
Temp. of C in °C →	...	...	...	....	...	...	.... $=\theta_2$

(E) *Time-temperature records of C during its cooling* :—

TABLE IV (Room temp. = ... °C)

Time in minutes t →	0	½	1	1½	2	2½	3	3½	4	4½	5	5½	6
Temp. of C in °C. θ →	....	...	...	....	...	...	...	...	....	....	....	...	....

(F) *Drawing of cooling curve for the lower disc C and to find* $\frac{d\theta}{dt}$:—

A curve is drawn with the temperature (θ) of C as the ordinate and the time (t) as abscissa [Fig. 41]. This is the cooling curve of C. Then a point (P, say) on the curve is selected, the value of whose ordinate is θ_2. A tangent is drawn to the curve at this particular point which makes an angle ϕ with the time-axis. Then the rate of cooling at θ_2 is given by

$$\frac{d\theta}{dt}=\tan\ \phi=\frac{\text{value of the ordinate at the point of the curve}}{\text{value of the intercept made by tangent on time-axis}}$$
$$=PN/NL.$$

Calculation :

$$K=\frac{ms\frac{d\theta}{dt}d}{A(\theta_1-\theta_2)}=\ldots=\text{. cal. per sec. per cm. per }^\circ C.$$

Corrected value of $(\theta_1-\theta_2)$ should be put in the formula to calculate K.

Discussions : (*i*) Noting of temperatures θ_1 and θ_2 of B and C respectively should be discontinued when they remain steady for at least 15 minutes.

(*ii*) The temperature of the lower disc C, during cooling, should be noted at intervals of half a minute, or more frequently if the rate of cooling be very rapid and it should be allowed to cool with the non-conducting sheet S on it.

(*iii*) To make the loss of heat by radiation from the sides of the sheet S a minimum, the diameter of the sheet should be made large in comparison with its thickness.

(*iv*) To find the rate of cooling of the disc C its position in the dynamical experiment should be the same, as it was kept in the steady state of temperature.

(*v*) Room-temperature during dynamical and steady state experiments should be noted to see whether the temperature of the surroundings is remaining the same during the two experiments.

(*vi*) The diameter of the sheet S should be made equal to those of B and C.

Oral Questions and their Answers

1—4. [Same as in Expt. 35].

5. Can this method be applied to the case of a liquid ?

If the disc S of the specimen is replaced by a thin-walled flat-end receptacle containing the liquid the method is applicable to find K of a liquid also.

6. Can you suggest any rough method of finding $d\theta/dt$ of the lower disc C at θ_2 ?

If the disc C be heated to some temperature θ_3 above θ_2 and allowed to cool to a temperature θ_4 as much below θ_2 as θ_3 is above it, then the rate of cooling of the disc C at θ_2 is approximately given by $(\theta_3-\theta_4)/t$, where t is the time taken by the disc C to cool from θ_3 to θ_4.

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CHAPTER IV

SOUND

37. *Meaning of some terms connected with accoustical experiments.*

(*i*) **Vibration** of a particle or of a body capable of vibration constitutes its *periodic to-and-fro movement.* The particle or the body is said to have performed *one complete vibration*, when starting from any point of its path it *next* comes back to the same point and begins to move in the same direction as before.

(*ii*) **Simple Harmonic Motion (S.H.M.)** of a particle is its periodic to-and-fro movement, in a straight line, such that the acceleration of the particle is proportional to its displacement from a fixed point in its path of motion and this acceleration is always directed towards that fixed point.

The vibration of the prong of a tuning fork is an example of S.H.M.

(*iii*) **Period (T)** of vibration of a particle is the time taken by the particle to perform its one complete vibration.

(*iv*) **Frequency (n)** of vibration of a particle is the number of complete vibrations which the particle performs in one second ; $n = 1/T$.

(*v*) **Amplitude (a)** of vibration of a particle is its *maximum displacement on either side* of its equilibrium position.

(*vi*) The **phase** of a vibrating particle at any instant of time is a quantity, which determines its *state of displcement and direction of motion* at that instant.

The phase of a vibrating particle at any instant is usually measured in terms of the *angle* (counted from a standard position) *which its corresponding revolving particle on the auxiliary circle describes at the centre of the circle* at that instant.

Two vibrating particles are said to be in the same or in the opposite phases according as their phase difference is even or odd multiples of π.

(*vii*) **Periodic force** is that whose magnitude and direction are changing regularly with time and they (magnitude and direction of the force) return to the same value after a *minimum interval of time* known as the *period* of the force.

(*viii*) **Free period** of a body capable of vibration is the period (T) with which the body vibrates when it is disturbed and *left to itself*.

(*ix*) When a periodic force is applied to a body capable of vibration so that the period (or frequency) of the applied force is different from the free period (or frequency) of the body, the body at first makes an irregular vibration and ultimately vibrates with a period (or frequency) equal to that of the applied force irrespective of its free period (or frequency). Such kind of vibration, which the body performs, is known as **forced vibration.**

When the stem of a vibrating tuning fork is held in contact with a hollow wooden board, the board performs a forced vibration and the sound of the fork is much intensified due to the vibration of the large volume of air in contact with the board.

(*x*) **Resonance** is a special kind of forced vibration in which the period (or frequency) of the applied force is equal to the free poriod (or frequency) of the body.

In resonance column experiment the sound of the tuning fork is much intensified due to resonance, which occurs when the frequency of the fork becomes equal to that of the fundamental tone or of any one of the overtones of the note produced by the vibration of the air column.

(*xi*) **Wave** is a disturbance which is communicated to a number of elastically bound particles placed in a row. The disturbance is gradually handed down from one particle to the next in the row. The phases of vibration of all the particles in the row are not the same ; they (phases) decrease regularly and systematically as we advance forward from the origin of disturbance to the other particles in the row one by one. None of the particles is displaced bodily from its own position but is simply vibrating about its mean positions. If the particles perform S. H. vibration during the propagation of the wave or disturbance, the wave will be called a Harmonic wave. The wave will be called **transverse** or **longitudinal**, according as the particles of the medium (through which wave is proceeding) vibrate at right angles to or along the direction of wave propagation.

Transverse wave comprises alternate crest and trough while the longitudinal wave comprises alternate compression and rareaction. The wave produced in a stretched string by plucking it with finger is an example of transverse wave. Sound waves in air or in any other gaseous medium are examples of longitudinal waves.

(*xii*) **Wavelength** (λ) of a wave is the distance by which the disturbance proceeds during one complete vibration of the particle at the origin of disturbance. It may also be defined as the *least distance* between two particles on the wave which are in the same phase of vibration.

(*xiii*) **Progressive wave** (which may be undamped transverse or longitudinal) is that which advances in all directions in an infinite homogeneous medium. All the particles, through which the wave proceeds, will perform the same kind of periodic motion and the amplitude and periodic time of all of them will be the same.

(*xiv*) **Stationary wave** is that which is produced by the superposition of *two identical waves* (which may be transverse or longitudinal) *travelling in opposite directions* with equal speed and in the same straight line.

The result of this superposition of two identical waves is, that some equidistant particles of the medium remain at rest for all times and the positions of these particles are known as **nodes.** In between two consecutive nodes there are particles which vibrate with the maximum amplitude and the positions of these particles are called **antinodes.** The distance between any two consecutive nodes or antinodes is half of the wavelength, *i.e.*

equal to $\lambda/2$, while the distance between a node and next antinode is $\lambda/4$.

This kind of wave may be produced in a *finite homogeneous medium* by the superposition of direct and reflected waves as are formed in the air column of the resonance column apparatus whose one end is open, while the other end is closed by water.

(*xv*) **Beats** are the phenomena arising out of the superposition of two *nearly* identical waves *travelling in the same direction*. When the waves from two sources of sound of *nearly equal frequencies* travel in the same direction, they (the waves from the two sources) by their superposition on a particle of the medium cause it to vibrate with an amplitude which varies periodically between maximum and minimum values. The periodic variation of the amplitude of the particle produces a periodic waxing and waning of the intensity of the resulting sound at that point which are known as **beats**. The number of beats per sec. (*i.e.* the number of maximum sounds per second or the number of minimum sounds per second) is equal to the difference of component frequencies.

(*xvi*) **Tone** is a pure sound having one definite frequency. The sound emitted by a vibrating tuning fork, when *not* struck violently, is a tone.

(*xvii*) **Note** is a complex sound which is formed by the mixture of several tones. The sound emitted by a string or an organ pipe is a note.

(*xviii*) When a note is analysed, we find the presence of a number of tones in the note. The tone in the note, whose frequency is the lowest, is called **fundamental tone**. The other tones in the note, whose frequencies are higher than that of the fundamental tone, are known as **overtones**.

If the frequencies of the overtones are simple integral multiples of that of the fundamental tone than those overtones are called **harmonic overtones** or **harmonics**. The frequencies of the harmonic overtones, which are produced by the vibration of the air column in the reasonance column apparatus are odd multiples of that of the fundamental. The transverse vibration of a stretched string produces a note in which the frequencies of the harmonic overtones are both odd and even multiples of that of the fundamental. The sound emitted by the vibration of a bell contains inharmonic overtones.

(*xix*) If the frequency of the sound emitted by a body A is double of that emitted by a body B, the frequency of A is said to be **octave higher** than that of B.

38. Determination of the velocity of sound in moist air at room-temperature by resonance column method and then to apply temperature and moisture corrections.

Apparatus : It consists of a long, wide and open-mouthed glass tube whose lower end is closed by a rubber cork. [Or the lower end is connected to a reservoir of water through a rubber tube. By raising or lowering this reservoir, the water level in the pipe can be raised or lowered]. Water from a reservior or from a tap can be introduced in the tube through an inlet pipe at its lower end. The water level in the tube can be raised or lowered or can be kept fixed at any position. There is a metre scale by the side of the tube by which the length of the air column in the tube from the open end to the water level can be determined. The arrangement is shown in Fig. 42.

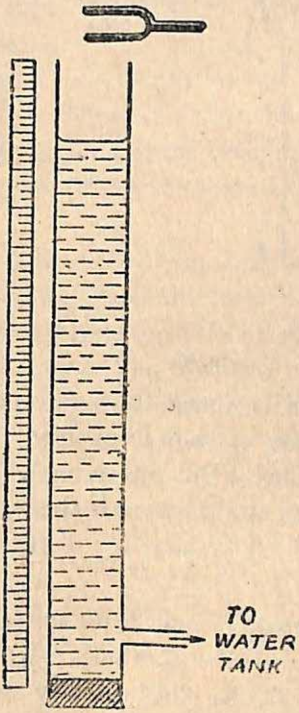


Fig. 42

Theory : When a vibrating fork is held over the mouth of a tube containing an air column of variable length, waves set up by the fork will proceed downward in the air of the pipe and will be reflected back from the water surface. The superposition of direct and reflected waves will set up stationary waves in the air of the pipe, in which water surface is always a node while the open end is always an antinode.

When resonance occurs with the shortest length (l_1) of the air column, the frequency of the fork becomes equal to that of the fundamental tone of the air column and the nature of this vibration is shown in Fig. 43(a). In this vibration, a node is formed at the water surface, while an antinode is formed at a distance x($x =$ [illegible] $\times d$ nearly, where d is the internal diameter of the pipe) above the mouth of the pipe.

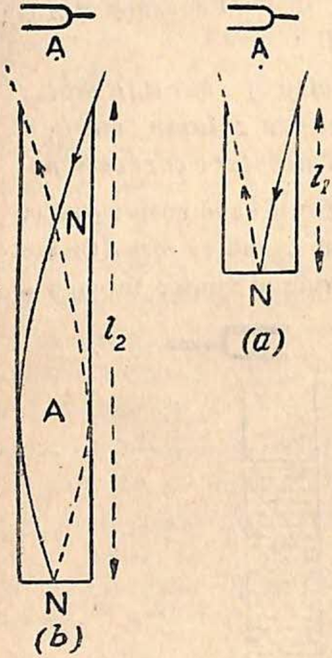


Fig. 43

Hence $l_1 + x = \lambda/4$. ... (1)

∵ the distance between a node and next antinode is $\frac{1}{4}$ of the wavelength (λ).

When the length of the air column is increased to l_2 (which is about $3l_1$), a second resonance occurs due to the equality of the frequency of the fork with that of the first overtone of the air column. The nature of vibration of the air column at this stage is shown in Fig. 43(b). Here we get,

$$l_2 + x = \frac{3\lambda}{4}. \quad \dots \quad \dots \quad \dots \quad (2)$$

From (1) and (2) we get $l_2 - l_1 = \lambda/2$, or, $\lambda = 2(l_2 - l_1)$.

Hence $V = n\lambda = 2n(l_2 - l_1)$.

If V_0 be the velocity of sound in dry air and at 0°C, the value of V_0 can be calculated from the observed value of V ... (3)

from the relation

$$V_0 = V\sqrt{\frac{B - \cdot 378f}{B}}(1 - \tfrac{1}{2}\alpha t). \quad \dots \quad (4)$$

By noting the barometric height B (in mm. of mercury) and by finding the saturation pressure of water vapour f (in mm. of mercury) at room temperature $t^\circ C$, we can calculate V_0 from (4), for $\alpha = \frac{1}{273}$ is known.

Procedure : (*i*) After determining the vernier constant of the scale of barometer, the height of mercury column (B mm.) is determined in the usual way from the scale and vernier attached to the barometer.

(*ii*) The temperature ($t^\circ C$) of air is determined by a thermometer attached to the barometer and the water vapour pressure (f mm.) at $t^\circ C$ is found out from a table.

(*iii*) The tuning fork of known frequency (n) is struck on a rubber pad and held over the mouth of the pipe. The water level, from the top of the tube, is gradually lowered until first resonance occurs for the *shortest length* of the air column. When resonance is about to occur, the water level is slowly lowered or raised until the maximum sound is obtained. The reading of the scale corresponding to this water level is noted. This is repeated thrice and the mean of these three readings gives l_1.

(*iv*) The water level is lowered down until the length of the air column becomes approximately three times the former length l_1. The water level is again slowly adjusted until the maximum sound is obtained for the *second time*. The readings of the scale corresponding to the water level is noted and this is also repeated thrice. The mean of these three readings gives l_2.

(*v*) By putting the mean values of l_1 and l_2 in equation (3), the velocity V of sound in moist air and at room temperature $t^\circ C$. is calculated ; for the frequency n of the fork is known.

Experimental data :

(A) *Noting of room temperature :—*

(*i*) Temp. before experiment $= t_1{}^\circ C. = \cdots{}^\circ C.$

,, after ,, $= t_2{}^\circ C. = \cdots{}^\circ C.$

Mean temp. during expt. $= t^\circ C. = \left(\frac{t_1 + t_2}{2}\right)^\circ C. = \cdots{}^\circ C$

(*ii*) Coefficient of cubical expansion of a gas $= \alpha = 1/273$ per °*C*.

(B) *Recording of barometric height* (*B mm.*) :—

Smallest scale division (*s.d.*) = ... *cm.*

... vernier divisions (*v.d.*) = ... *s.d.*

1 *v.d.* = ... *s.d.*

∴ Vernier constant (*v.c.*) = 1 *s.d.* − 1 *v.d.* = ···*s.d.* = ···*cm.*

TABLE I

Time of record	Scale reading in cm. (*S*)	Vernier reading in cm. (*V*) = (*v.r.*) × (*v.c.*)	Total reading in cm. $B=(S+V)$	Mean barometric height (*B*) in mm.	Vapour pressure (*f*) of water in mm. of mercury at *t*°C
Before expt.	...	(...) × (...) = ...	...	....	...
After expt.	...	(...) × (....) = ...	....		

(C) *Recording of resonant lengths of air column* :—

TABLE II

Frequency of known fork (*n*)	Length in cm. of,				$V = 2n(l_2 - l_1)$ cm/sec. at *t*°C	Mean V in cm./sec.
	First resonance (l_1)	Mean (l_1)	*Second* resonance (l_2)	Mean (l_2)		
...(n_1)	... .	....	... .	....	...	...
...(n_2)	... ...	....	....	...	...	

Calculation :

(*i*) $V = 2n(l_2 - l_1) =$ .. = ... = cm./sec. at *t*°*C*.

(*ii*) $V =$ ··· = ···cm:/sec. at *t*°*C*.

(*iis*) $V_0 = V\sqrt{\dfrac{B - 378f}{B}}\,(1 - \tfrac{1}{2}\alpha t)$ = ··· = ·· cm./sec.

Precautions : (*i*) To get first resonance the length of the air column should be increased from a *low value.*

(*ii*) Near resonance, the water level should be changed *very slowly* and should be kept fixed at the position where maximum sound will be heard.

(*iii*) If the length of the *resonance tube is not very large,* then the frequency of the known fork *should not be very low* otherwise second resonance will not be obtained.

39. Determination of the velocity of sound in moist air at room temperature and hence to determine the frequency of an unknown fork.

Apparatus : [Same as in Expt. 38, Fig. 42.]

Theory : [Write the theory of Expt. 38 up to equation (3) and then *add* the following paragraph].

If l_1' and l_2' are respectively the first and second resonant lengths with the fork of unknown frequency n' then from eqn. (3) we may write,

$$V = 2n'(l_2' - l_1')$$

$$\text{or,} \quad n' = V/2(l_2' - l_1') \qquad \cdots \qquad \cdots \quad (4)$$

Knowing V from eqn. (3), n' can be found out from eqn. (4)

Procedure : (*i*), (*ii*) & (*iii*)—[Same as the items (*iii*), (*iv*) and (*v*) respectively of 'Procedure' in Expt. 38.]

(*iv*) The above two operations (*i*) and (*ii*) are repeated with the fork of unknown frequency n' and the mean values of the first resonant length (l_1') and second resonant length (l_2') are determined. The unknown frequency n' is then calculated from (4) by putting the value of V obtained from eqn. (3).

Experimental data :—

Temperature at the beginning of experiment $= t_1°C = \cdots °C$.
" " " " " " $= t_2°C = \cdots °C$.

Thus the temperature during experiment is almost steady.

TABLE I

Frequency of the fork (n)	Lengths in cm. of,				Result (velocity or frequency)	
	First resonance (l_1)	Mean (l_1)	*Second* resonance (l_2)	Mean (l_2)	$V = 2n(l_2 - l_1)$ cm./sec.	Mean V
	...		...			
Known ....(n_1)	...	....	....	...	...	$V =$
	...		...			...
	....		...			
...(n_2)	...	...	....	...	...	cm./sec.
	...		..			
Unknown	...		...		Frequency = $n' = \frac{V}{2(l_2' - l_1')}$	
	....	...	....	...	=	
(n')	....	$= l_1'$	....	$= l_2'$	vibrations per sec.	

Calculations :

(*i*) $V = 2n(l_2 - l_1) = \cdots = \cdots$ cm. per sec.
etc. etc.

(*ii*) $n' = \frac{V}{2(l_2' - l_1')} = \cdots \qquad = \cdots$ vibrations per sec.

Precautions : (*i*) & (*ii*)—[same as in Expt. 38.]

(*iii*) If the resonance tube is not sufficiently long, then the frequency of both known and unknown forks should not be very low, otherwise second resonance will not be obtained.

40. To-draw (n − l) curve with resonance column of air and hence to find the frequency of an unknown fork.

Apparatus : [Same as in Expt. 38. Fig. 42.]

Theory : [Write the theory of Expt. 38, up to the equation (1) and then *add* the following paragraph.]

But the wavelength λ of the wave is given by, $\lambda = V/n$. Hence $l_1 + x = V/4n$. If $l_1 + x = l'$ = corrected length between a node and next antinode then $l' = V/4n$. Thus at a constant temperature (when V is constant), $l' \propto 1/n$. If a graph be drawn with the frequency (n) along x-axis and the corrected length (l') along y-axis, then the graph would be a rectangular hyperbola. From this curve, the frequency of an unknown fork corresponding to its first resonant length can be found out.

Procedure : (*i*) The internal diameter of the mouth of the pipe is measured in several directions by a slide callipers and from the mean value (d) of these diameters, the end correction x of the pipe, ($x = \cdot 3d$) is found out.

(*ii*) A set of tuning forks (usually eight) are taken, the frequencies of all of which are known excepting one. These forks are then kept arranged on the table in the descending order of their frequencies keeping the unknown fork at the last place.

(*iii*) The tuning fork of highest frequency is struck on a rubber pad and held over the mouth of the pipe which is almost full of water. The water level from the top of the tube is gradually lowered until first resonance occurs for the shortest length of the air column. When resonance is about to occur, the water level is to be raised or lowered very slowly until maximum sound is heard. The length of the air column in the pipe is measured by a scale. This is repeated for three times and the mean of these three shortest lengths gives l_1. When $\cdot 3d$ is added to this l_1 we get the corrected shortest length (l') of the air column for the first fork.

(*iv*) The above operation (*iii*) is repeated for the remaining forks, taking one by one in the descending order of frequencies in which they are kept arranged. Lastly, the operation (*iii*) is also performed for the unknown fork. In each case the corrected length (l') is found out.

(*v*) A graph is now drawn with the frequencies (n) of known forks as abscissa and their corresponding corrected lengths (l') for first resonance as ordinate. The graph would be a rectangular hyperbola. From this graph, the frequency of the unknown kork, corresponding to its corrected first resonant length is found out.

Experimental data :

(A) *Internal diameter* (d) *of the pipe by slide callipers* :—

Value of the smallest scale divisions ($s.d.$) = ... cm.

$\ldots v.d. = \ldots s.d.$; $\therefore\ 1\ v.d. = \ldots s.d.$

$\therefore\ v.c. = 1\ s.d. - 1\ v.d. = (\ldots - \ldots)\ s.d. = \ldots$cm.

Instrumental error = ... cm.

TABLE I

No. of obs.	Main scale reading in cm. (S)	Vernier reading in cm. (V) $=(v.r.)\times(v.c.)$	Total reading in cm. $=d$ $=(S+V)$	Mean corrected diameter (a) in cm.	End correction $=x=\cdot3d$ cm
1.	...	(....) × (....) =...	...	....	...
2.	...	(....) × (....) =	....		
etc.					
4.	....	(...) × (....) =....	....		

(B) *Frequency – Resonant length records* :—

Temperature before experiment $= t_1$ °C. = .. °C.

,, after ,, $= t_2$ °C. = .. °C.

TABLE II

No. of obs.	Frequency of the fork (n)	First resonant length (l_1) in cm.	Mean l_1 in cm.	Corrected length $=$ $l'=l_1+\cdot3d$ in cm.	Frequency of unknown fork from graph.
1.	512	....	...	...	... vibrations per sec.
2.	480	... ...	...	....	
etc.	etc.	etc.	etc.	etc.	
7.	256	... .	...	...	
8.	Unknown	....	...	...	

(C) *Drawing of $(n-l')$ curve* :—

[Procedure is the same as the drawing of $(n-l)$ curve with sonometer. See item (*B*) of experimental data of Expt. 43].

Precautions : (*i*) & (*ii*)—[Same as (*i*) and (*ii*) of Expt. 38]. (*iii*) First resonant length (l') will vary inversely with the frequency, provided the velocity of sound is constant. As the velocity changes with temperature, the recording of temperatures before and after the experiment should be made, to know whether there is any appreciable variation of it during the experiment.

(*iii*) Determination of the frequency of the unknown fork will be better done from the *straight line curve*, obtained by plotting n along x-axis and $1/l'$ along y-axis than from the smooth curve connecting frequency (n) and corrected first resonant length (l').

Oral Questions and their Answers

1. What do you mean by the terms : forced vibration and resonance ? What is the difference between the two ?

[See Art. 37, items (*ix*) and (*x*).]

2. What is the distinction between a tone and a note ?

[See Art. 37, items (*xvi*) and (*xvii*).]

3. What is the difference between overtones and harmonics ?

[See Art. 37, item (*xviii*).]

4. Do you consider the sounds emitted by the tuning fork and the air column in the pipe, as tones or notes ?

The tuning fork produces a tone when it is *not* struck violently while the air column in the resonance pipe always produces a note.

5. What are stationary waves ? How are nodes and antinodes produced ?

[See Art. 37, items (*xiv*).]

6. What are transverse and longitudinal waves ? What do you mean by wavelength ? [See Art. 37, items (*xi*) and (*xii*).]

7. What tones of the air column are in resonance with the fork ?

The first resonance occurs between the tuning fork and the fundamental tone of the air column while second resonance occurs between the tuning fork and first overtone of the air column.

8. Is it possible to obtain more than two resonances in the pipe ?

Yes : when the length of the air column is about 5 times of that required for first resonance, we shall get third resonance between the tuning fork and second overtone of the air column.

9. Are the overtones emitted by the air column harmonics ?

Yes, frequencies of overtones are odd multiples of that of the fundamental and hence the overtones are harmonics.

10. What is an end error ?

The antinode at the mouth of the tube is formed at some distance x above it and this distance is a measure of the end error which is approximately $= \cdot 6 \times$ (radius of tube).

11. Will the resonant length vary, when the temperature and pressure of air in the pipe vary.

Increase of temperature will cause an increase of velocity in air and hence $(l_2 - l_1)$ will increase for the frequency (n) of the fork is constant. Velocity is independent of pressure and hence $(l_2 - l_1)$ will remain unaffected with the change of pressure.

12. How will the resonant length be affected with the change in the nature of the gas in the pipe ?

If the density of the gas be high, then V will be less and $(l_2 - l_1)$ will also be less.

13. How does the reflection of waves take place in resonance pipe ?

The vibrations of the tuning fork at the mouth of the pipe produce alternate compressions and rarefactions which will be reflected from the water surface without any change of sign.

41. Determination of the frequency of a tuning fork by a sonometer.

Apparatus : The sonometer employed here is a monochord which consists of a hollow resounding wooden box W on the upper surface of which a fine uniform steel wire SS is kept stretched [Fig. 44].

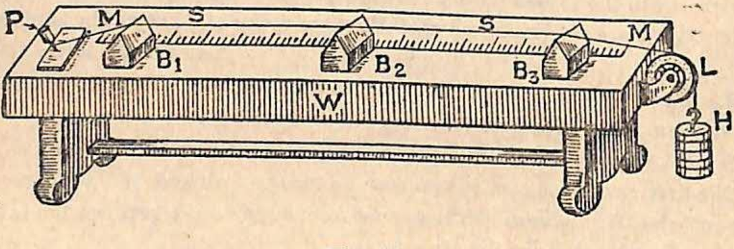


Fig. 44

The wire passes over the two fixed bridges B_1 and B_3 at the two ends of the box. One end of the wire is attached to a pin P while its other end passes over a pulley L and is attached to a hanger H on which loads can be placed to stretch the wire. There are two movable bridges like B_2 below the wire by moving which the vibrating length of the wire can be altered. There is metre scale MM by the side of the wire by which its vibrating length can be measured.

Theory : When a flexible stretched string of finite length l is plucked, transverse waves will proceed along the string with a velocity $V=\sqrt{\frac{T}{m}}$ where T and m are the tension (in dynes) and mass (in gms.) per unit length of the string respectively. These waves will be reflected from the fixed ends of the string and will superpose on the direct waves forming stationary waves, in which nodes and antinodes will be produced. If the string vibrates in its fundamental or simplest form, then it will vibrate in one segment only [Fig. 45] having nodes at the two fixed ends and an antinode at the middle, so that $l=\lambda/2$, or $\lambda=2l$.

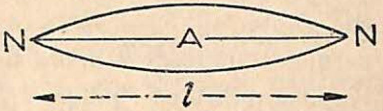


Fig. 45

$$\text{Now,}\quad V=n\lambda=\sqrt{\frac{T}{m}}.$$

$$\therefore\quad n=\frac{1}{\lambda}\sqrt{\frac{T}{m}}=\frac{1}{2l}\sqrt{\frac{T}{m}}\ [\text{ for fundamental vibrations }].$$

If the mass of the hanger be m_h gms. and the load on the hanger be W kilos, then the total stretching load $=M=(1000\,(W+m_h)$ gms. Hence the tension of the string is, $T=Mg$ dynes.

$$\therefore\quad n=\frac{1}{2l}\sqrt{\frac{Mg}{m}}=\frac{1}{2}\sqrt{\frac{g}{m}\cdot\frac{M}{l^2}}\qquad\cdots\qquad\cdots\quad(1)$$

If the given unknown fork is brought in unison with the length l of the string, emitting its *fundamental tone*, then the frequency (n) of the fork will be equal to that of the string and hence n can be calculated from the relation (1).

Procedure : (*i*) First, the mass per unit length (m) of the string is to be determined. For this purpose, a *sample wire* is taken and its length (L) is measured accurately by a scale while its mass (w) is determined by a balance. Hence mass per unit length m ($=w/L$ gms. per. cm.) is determined. Weighing should be made either by observing equal displacements of the pointer on both sides of the central line (in which a rider is to be employed) or better by oscillation method.

The unloaded hanger (H) is detached from the wire and its mass (m_h gms.) is determined by a balance (usually the value of m_h is supplied). Then it is kept tied to the end of the wire.

(*ii*) A suitable load, of W kg. (say 2 kg.) is placed on the hanger to give some tension to the wire, so that the total stretching load of the wire is $M=(1000W+m_h)$ gms. The two movable bridges below the wire are then kept separated by a very small distance until the sound emitted by the string is shriller (high pitch) than that of the fork.

(*iii*) The prong of the fork is struck by a hammer and its stem is held on the board when a loud sound is heard due to the forced vibration of the board. The string is plucked by hand when another sound will be heard. The position of one of the movable bridges below the wire is then shifted slowly to increase the length of the wire between the two bridges until these two sounds are in unison. At this unison, (1) a small paper rider placed on the wire will be thrown down when the stem of the vibrating fork is held in contact with the board and (2) beats between the sounds of the fork and the string will disappear. As this unison occurs with the shortest length of the wire, we conclude that this unison occurs between the fork and the fundamental tone of the string. [A preliminary adjustment may be made to find the approximate position of unison of the string. For this purpose, the movable bridges should be kept at a sufficient distance apart. The central region of one prong of the vibrating fork is made to touch the wire *very lightly* near one bridge and it is slided on the wire towards the second movable bridge until at a particular point of the wire, a sharp cracking sound is heard. This point of the wire is the approximate position of unison. The first movable bridge is then brought to this position of the string and the exact position of unison is then determined by employing the methods described in (1) and (2).]

(*iv*) The length of the wire between the two movable bridges is measured by a scale and this observation of finding the *minimum length* of the wire which is in unison with the fork is repeated thrice. The mean of these three observations gives the resonant length (l) of the wire, from which M/l^2 is found out.

(*v*) The operations (*ii*) to (*iv*) are repeated with two other loads (say 2·5 kg. and 3 kg. on the hanger and in each case the ratio of the total stretching load M in gms. to the square of the corresponding mean shortest resonant length l in cm. of the wire (*i.e.* M/l^2) is found out. The mean value of M/l^2 from these three observations, when put in the eqn. (1) we get n the frequency of the unknown fork.

Experimental data :

(A) *Mass per unit length* (m) *of the string* :—

TABLE I

Length of sample string in cm. (L)	Mean L in cm.	Mass of the sample string in gms. (w)	Mass per unit length of the sample $= m = w/L$ gms. per cm.
...		...mg.+....mg.+	
...	....	...mg.+...	...
...		=...gm.	

N.B. [If the mass is to determined by oscillation method then make another chart [as in Expt. 12(b)] before Table I and take each resting point P, Q and R only once.]

(B) *Load—Resonant-length records* :—

TABLE II

Mass of the hanger $= m_h =$ ··· gms.

No. of obs.	Load on the hanger in kilos (W)	Stretching load of the wire in gms $= M = (1000W + m_h)$	Resonant length in cm. (l)	Mean l in cm.	Value of M/l^2	Mean M/l^2	Frequency (n)
1.	2	...	... ...	...	...	....	... vibrations per sec.
2.	2·5	...	... .	...	...		
3.	3 ..	...	....	...	...		

N.B. [The magnitude of the maximum load applied, will depend on the diameter of the wire, and it should be below half of the breaking load of the wire. For the same string, M/l^2 should be nearly constant.]

Calculations :

$$n = \frac{1}{2}\sqrt{\frac{g}{m} \cdot \frac{M}{l^2}} = \cdots\cdots\cdots\cdots = \cdots\cdots\cdots\cdots \text{vibrations/sec.}$$

[By putting the values of m from Table I and mean M/l^2 from Table II].

Precautions : (*i*) To avoid resonance between the fork and the higher tones of the string, always the *shortest length* of the string should be brought in resonance with the fork. In that case resonance will occur between the fork and the fundamental tone of the string and the formula employed would be correct.

(*ii*) The string should be plucked in such a way that the intensity of the sound emitted by the fork and the string should be of the same order, otherwise beats cannot be heard clearly.

42. *To determine the density of the material of a wire by employing sonometer.*

Apparatus : [Same as in Expt. 41, Fig. 44.]

Theory : [Write the theory of experiment 41 up to the equation (1) and then *add* the following paragraph.]

If ρ and d are respectively the density and diameter of the sonometer wire, then, $m=\pi d^2\rho/4$. Hence the equation (1) reduces to,

$$n=\frac{1}{2}\sqrt{\frac{g}{m}\cdot\frac{M}{l^2}}=\frac{1}{2}\sqrt{\frac{4g}{\pi d^2\rho}\cdot\frac{M}{l^2}};$$

$$\text{or, } \rho=\frac{g}{\pi n^2 d^2}\left(\frac{M}{l^2}\right) \quad \cdots \quad \cdots \quad \cdots \quad (2)$$

The eqn. (2) may be employed to find ρ.

Procedure : (*i*) The diameter (d) of the sonometer wire is measured at its five or six different places by a screw gauge and at each place the readings are taken in two directions at right angles to each other. When the mean diameter is corrected for the instrumental error of screw gauge, we get the exact value of d.

(*ii*), (*iii*) and (*iv*)—[Same as the operations (*ii*), (*iii*) and (*iv*) of 'procedure' of Expt. 41.]

(*v*) The operations (*ii*) to (*iv*) are repeated with two other loads (say 2·5 *Kg*. and 3 *Kg*.) on the hanger and in each case the ratio of the total stretching load M in gms. to the square of the corresponding mean resonant length (l) in cm. of the wire [i.e. M/l^2] is found out. The mean of these three values of M/l^2 when put in the equation (2) we get ρ, the density of the sonometer wire.

Experimental data :

(A) *To find the diameter* (d) *of the sonometer wire* :—

TABLE I

[Make a screw gauge chart as in Expt. 8 and take observations at least in six different places of the wire.]

(B) *Load—resonant length records* :—

Mass of the hanger $= m_h =$ ······gms.

The frequency of the given fork $= n =$ ······vibrations per sec.

TABLE II

No. of obs.	Load on the hanger in kilos (W)	Total stretching load of the wire in gms. $= M = (1000W + m_h)$	Resonant length in cm. (l)	Mean l in cm.	M/l^2	Mean M/l^2	Density of wire in gms./c.c. (ρ)
1.	2	...	... .	...	...	...	....
2.	2·5	...	... ...	....	....		
3.	3	....	... ...	...	...		

Calculations :

$$\rho = \frac{g}{\pi n^2 d^2}\left(\frac{M}{l^2}\right) = \cdots\cdots = \cdots\cdots \text{gms./c.c.}$$

[By putting the values of n (given), d from Table I and mean M/l^2 from Table II ρ can be calculated.]

Precautions : (*i*) & (*ii*)—[Same as (*i*) and (*ii*) of precautions of Expt. 41.]

(*iii*) As l and d occur in square powers in the expression for ρ, their values should be determined as accurately as possible.

Oral Questions and their Answers

1 to 3. Same as at the end of Expt. 40.

4. Why is the sound of a tuning fork intensified when its stem is pressed against the board?

The board makes a forced vibration, as a result, the large volume of air in the box is set into vibration and the sound is intensified.

5. If the load is increased, then will the resonant length increase or decrease?

Increase ; for as M increases, l must increase to keep n constant.

6. How does the diameter and density of the wire affect its frequency ?

If the change in the diameter and density of the wire causes an increase in the mass per unit length of the vibrating string, then the frequency will decrease and the reasonant length (l) of the string will have to be made shorter so that it may be in unison with the given fork.

7. After obtaining unison between the fork and the string, if you double or halve the length of the string alone, will you still get resonance ?

The fork emits a pure sound, *i.e.* tone while the string emits a note the frequencies of whose overtones are simple multiples of that of the fundamental tone. When the length of the string is doubled, the frequency of its first overtone becomes equal to that of the fork and hence resonance will be obtained between them but the sharpness of this resonance is very small and usually escapes unnoticed. When the length of the string is halved, the frequency of its fundamental tone will be double that of the fork and at this time resonance cannot be expected for the fork emits a tone.

8. By what process can you make the string emit a sound which is an octave higher than at present ?

By making the length of the string half, or by increasing the tension 4 times than at present ?

9. How do you understand that the fork is in resonance with the fundamental tone of the string ?

The sharpness of resonance will be very great and the paper rider on the string will be violently thrown away. Again the string will vibrate in one segment only and the sounds emitted by the fork and the string, as heard by the ear, will appear to be of the same pitch ?

10. Would you prefer a thick or thin wire for your experiment ?

Thin wire. If the wire be thick, rigidity of the wire, in addition to its tension, will play an important part in the controlling factor and in that case the formula employed in calculating n or ρ will not be accurate.

43. To draw (n-l) curve for a sonometer wire under constant tension and hence to find the frequency of an unknown fork from graph.

Apparatus : [For description of a sonometer, see Expt. 41.]

Theory : The frequency (n) of transverse vibration of a stretched string is inversely proportional to its length (l), when the tension T and mass per unit length (m) of the string are constants.

or, $n \propto 1/l$, when T and m are constants.
or, $n \times l =$ constant, when T and m are constants.

If a curve is drawn with various values of l plotted along the y-axis while the corresponding values of n along the x-axis, then the curve would be a rectangular hyperbola. From this curve the unknown frequency n' for a given resonant length l' can be found out.

Procedure : (*i*) A set of tuning forks (usually eight) are taken the frequency of one of which is unknown while those of the rest are known. They are kept arranged on the table in the descending order of their frequencies keeping the unknown fork at the last place. The wire is loaded by such a load that an appreciable resonant length is obtained for the highest frequency fork. This load on the hanger is kept *fixed* throughout the experiment.

(*ii*) The fork of highest frequency is struck on a rubber pad and its stem is pressed against the sonometer board, when a sound is produced. Another sound is produced by plucking the portion of the string between the two movable bridges. Unison between these two sounds is now brought about by moving slowly one of the movable bridges (which was placed very close to the other movable bridge), so that the length of the string between the two bridges may increase gradually from a *low value*. When unison occurs, a small paper rider placed on the string will be violently thrown down, when the stem of the vibrating fork is pressed against the sonometer board and also the beats between the two sounds will be found to disappear. [An approximate state of resonance between the fork and the string can be obtained by a preliminary adjustment as was described in procedure (*iii*) of Expt. 41.] The distance between the two movable bridges is measured by a scale and this observation is repeated thrice. The mean of these three observations gives the length of the string which is in resonance with the fork taken.

(*iii*) The operation (*ii*) is repeated for the remaining forks in the descending order of their frequencies and lastly the operation (*ii*) is repeated for the unknown fork.

(*iv*) A graph is now drawn with the resonant length (l) of the wire along the y-axis while the corresponding frequency of the known forks along the x-axis. A smooth curve is drawn through the majority of points. From this curve, the frequency n' of the unknown fork corresponding to its resonant length l' is determined.

Experimental data :

(A) *Frequency-resonant length data* :—

Fixed load on the hanger = ... *kg.*

No. of Obs.	Frequency of the fork	Resonant length (l) in cm.	Mean l in cm.	Frequency of the unknown fork from graph
1.	512	... ...	...	... vibrations per sec.
2.	480	... .	...	
3.	426·6	....	...	
etc.	etc.	etc.	etc.	
7.	256	... .	...	
8.	Unknown	....	...	

(B) *Drawing of* $(n-l)$ *curve* :—

To draw $(n-l)$ curve, the frequencies (n) of the known forks are plotted along the x-axis, while their corresponding resonant lengths (l) are plotted along the y-axis. Round numbers, which are smaller than the minimum data for n and l, are selected as their respective origins. The representations along the two axes are made in such a way that the data obtained by experiment cover the whole of the graph paper supplied. (For procedure of drawing graph, see Article 5). The curve obtained by joining the points would be a rectangular hyperbola, the nature of which is shown in Fig. 1. From this graph the unknown frequency corresponding to its resonant length (obtained by experiment) is found out.

[The frequency of an unknown fork can be best determined from the straight line obtained by plotting n along the x-axis and $1/l$ along the y-axis, than from a smooth curve obtained by plotting n along the x-axis and l along the y-axis.]

Precautions : [Same as in Experiment 41.]

Oral Questions and their Answers

[Same as those of Experiments 41 and 42.]

44. Determination of the frequency of a tuning fork by Melde's apparatus.

(a) Transverse arrangement.

Apparatus : Melde's apparatus is shown in Fig. 46. It

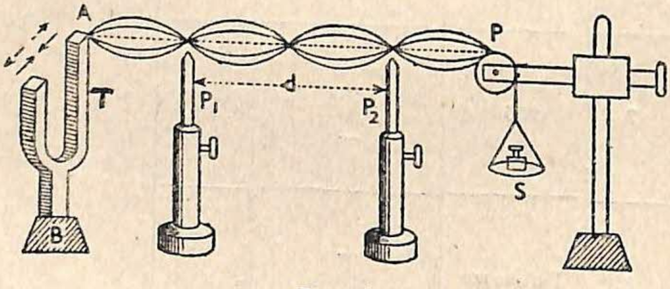


Fig. 46

consists of a light silk string (AP), about a metre long. One end A of the string is attached to one prong of a tuning fork T, which is screwed vertically on a wooden base B. The other end of the string passes over a pulley (P) and is attached to a scale pan (S), on which loads can be placed to stretch the string. The position and height of the pulley are adjustable, so that the string may remain horizontal. In one position of the fork (transverse arrangement) its prongs vibrate perpendicular to the length of the string, while in its another position (longitudinal arrangement) the prongs vibrate along the length of the string.

Theory : When the prongs of the fork vibrate, transverse waves will proceed along the length of the string and they on reaching the distant end of the string will be reflected back. The superposition of the direct and reflected waves will form stationary waves, in which the extreme fixed ends (A and P) of the string will always be nodes and in between them there may be one or more number of antinodes depending on the load placed on the scale pan S.

When the length and the tension of the string are adjusted to make the frequency (N) of the fork equal to that of the fundamental or any one of the higher tones of the string, a resonance will occur between the fork and the particular mode of vibration of the string. At this stage the amplitude of vibration of the string at the antinodes will be greatest.

The velocity V of transverse waves along a string of linear density m (in gms. per cm.) and stretched by a tension T (in gms.-wt.) is given by $V=\sqrt{\frac{Tg}{m}}$. ... ... (1)

But the frequency (n) of vibration of the string is given by

$$n=\frac{V}{\lambda}=\frac{1}{\lambda}\sqrt{\frac{Tg}{m}}. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

In transverse arrangement the frequency N of the fork is equal to that of the string (n). Hence

$$N=\frac{1}{\lambda}\sqrt{\frac{Tg}{m}}=\sqrt{\frac{g}{m}\cdot\frac{T}{\lambda^2}}. \quad \ldots \quad \ldots \quad (3)$$

Knowing m and T/λ^2, the frequency N of the fork can be calculated from (3).

Procedure : (*i*) A silk string (about a metre long) is taken and its length (L) is measured thrice by a metre scale. The mass (w) of the string is determined very accurately by a balance by using a centigramme rider. The mass per unit length $m(=w/L)$ is thus determined. The mass (Q) of the scale pan S is also found out. The silk string and the scale pan are now set up in the apparatus as shown in Fig. 46.

(*ii*) A certain load (M) [say, 10 gms.] is placed on the scale pan and the fork is made to vibrate either electrically or by drawing a resined bow at right angles to one prong of the fork or by giving a light blow to one prong of the fork by a rubber-padded hammer. At this time ill-defined nodes and antinodes will be seen. The length of the thread is now adjusted until the nodes and the antinodes are clearly depicted. At this time resonance occurs between the fork and the particular mode of vibration of the string.

(*iii*) Two pins (P_1 and P_2) of adjustable heights are placed below the two extreme well-defined nodes (but *not* below the nodes at the two ends of the string) and the distance d between them is measured by a scale. The number of loops (k) between the pins are also counted. This operation is performed thrice by independently adjusting the length of the thread and the positions of the pointer. The mean of the three value of d when divided by k gives half the wavelength λ. Thus $\lambda = 2d/k$ is obtained for this particular load.

(*iv*) The operations (*ii*) and (*iii*) are repeated for two other increasing loads (by which the number of loops will decrease).

(*v*) The tension T (in gms.-wt.) of the string is given by $(M+Q)$ gms.-wt.

Experimental data :

(A) *Determination of linear density* (m) *of the string and the mass* (Q) *of the scale pan :—*

TABLE I

Length of the thread in cm. (L)	Mean L in cm.	Mass of the thread in gms. (w)	Mass per unit length of the thread $=m=w/L$ gms./cm.	Mass of the Scale pan in gms. (Q)
...		... + ... +		...+...+
...	....	... + ...	...	...+...
....	$=L$	=...$=w$		=...$=Q$

(B) *To find the wave length* (λ) *in the string* :—

TABLE II

No. of obs.	Load on the pan in gms. (M)	Distance between the pins in cm. (d)	Mean d in cm.	No. of loops between the pins (k)	Wavelength $=\lambda=\frac{2d}{k}$ cms.
1.	...	... .	....	...	...
2.	...	... ...	...	....	....
3.	...	... ...	...	...	...

(C) *To find the frequency* (N) *of the fork* :—

TABLE III

Obs.	Tension of the string $=T=(M+Q)$ gms.-wt. [from tables I and II]	Wavelength in cm. (λ) [from table II]	Value of T/λ^2	Mean T/λ^2	Frequency of fork $=N$ $=\left(\frac{g}{m}\cdot\frac{T}{\lambda^2}\right)^{\frac{1}{2}}$
1.	....	...	....		
2.	....	...	...	....	...
3.	...	...	...		Vibrations per sec.

Calculation :

$$N=\sqrt{\frac{g}{m}\cdot\frac{T}{\lambda^2}}= \quad \cdots \quad = \quad \cdots \quad \text{vibration per sec.}$$

[The value of m from Table I and the mean value of T/λ^2 from Table III are to be put in the formula to calculate N.]

Precautions : (*i*) The vertical portion of the string, *i.e.*, the portion of the string between the pulley and the scale pan, should be as small as possible. Otherwise the mass of this portion of the string should be added to $(M+Q)$ to get the tension in gms.-wt.

(*ii*) The experiment should be begun with a small load (M) on the pan, so that the number of loops may be six. Then the load should be increased in order to decrease the number of loops to 4 and 2 respectively. If T be the load for one loop then the load T_k for k loops is given by $T_k=T/k^2$, when the length of the string is constant. The number of loops (k) can also be increased by increasing the length of the string when the tension is constant. If l be length required for one loop, the length required for k loops would be $l_k=kl$, when the tension is kept constant.

(*iii*) As the nodes at the two ends (A and P) of the string are not distinct, the pointers should be placed below the nodes which are next to the nodes at A and P.

(*iv*) The string should be of as uniform a linear density as possible. For this purpose a fishing line is very suitable.

(b) Longitudinal arrangement.

Apparatus : [Same as in the Transverse arrangement]

Theory : [Write the theory of transverse arrangement up to equation (2) and then *add* the following paragraph.]

In longitudinal arrangement the frequency N of the fork is double the frequency (n) of the string. Hence,

$$N=\frac{2}{\lambda}\sqrt{\frac{Tg}{m}}=2\sqrt{\frac{g}{m}\cdot\frac{T}{\lambda^2}}. \quad \cdots \quad \cdots \quad (3)$$

From the knowledge of m and T/λ^2, the frequency N of the fork can be calculated from the equation (3).

Procedure : [Same as in Tranverse arrangement.]

Experimental data : [Same as in Transverse arrangement.]

Calculations :

$$N=2\sqrt{\frac{g}{m}\cdot\frac{T}{\lambda^2}} = \quad \cdots \quad = \quad \cdots \quad \text{vibration per sec.}$$

[The value of m from Table I and the mean value of T/λ^2 from Table III are to be put in the formula to calculate N.]

Precautions : [Same as in Transverse arrangement.]

Oral Questions and their Answers

1. How does the transverse arrangement differ from longitudinal arrangement ?

When the same fork is employed for resonance in the same string stretched by the same tension the frequency of the *string* in the longitudinal arrangement will be half of that in the transverse arrangement.

2. If the number of loops in the two arrangements are to be kept same, in what way their tensions will vary ?

The tension in the longitudinal arrangement will be one-fourth of that, in the transverse arrangement.

3. If the tension in the two arrangements are kept same, in what way the number of loops in them will alter ?

The number of loops in longitudinal arrangement will be half of those in the transverse arrangement.

4. Why the length of the string between the pulley and the scale pan is kept short ?

Otherwise the appreciable mass of this portion of the string will increase the tension of the string.

5. How do you know that resonance has occurred between the fork and the string ?

When the amplitude of vibration at the antinodes is greatest we conclude that the desired resonance has occurred.

6. What are stationary waves, nodes, and antinodes. [see Art 37 item (*xiv*)]

7. Does the note emitted by the string contain harmonic or inharmonic overtones ?—Harmonic overtones, the frequencies of the overtones are both odd and even multiples of that of the fundamental tone.

8. Can you perform your experiment with a thick wire ?

In that case the rigidity of the wire, in addition to its tension, will have controlling force and the simple formula employed will not hold good.

CHAPTER V

MAGNETISM

45. Magnetometers.

(a) Deflection Magnetometer.

It consists of a long wooden board of rectangular cross-section, at the middle of which a circular magnetometer box with a glass top is fixed [Fig. 47]. The box contains a circular scale graduated separately in four quadrants from 0° − 90°, so that the (0° − 0°) line is usually parallel to the axial line of the board. At the centre of this circular scale a *short magnetic needle* (*ns*) is pivoted. At right angles to this needle a long aluminium pointer is fixed, so that the ends of the pointer may move over the circular scale.

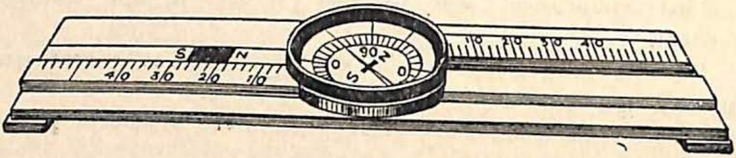


Fig. 47

A circular strip of mirror is usually placed below the pointer, so that the readings of the pointer may be taken by avoiding parallax. Two metre-scales are fixed on the board on the two sides of the magnetic needle, so that the zeros of these two scales coincide with the centre of the needle. The magnet (NS) can be placed along or perpendicular to the length of the board. When the length of the wooden board is perpendicular to the magnetic meridian, the magnet should be placed with its length along the board and this position of the magnet is called the 'Tangent *A*-position of Gauss'. At this time the pointer usually reads (0° – 0°) of the circular scale. If the rectangular board is placed along the magnetic meridian, the magnet should be placed with its length perpendicular to the board and this position of the magnet is called the 'Tangent *B*-position of Gauss'. This time the pointer usually reads (90° – 90°) of the circular scale. The arrangement is shown in Fig. 47.

(b) The vibration magnetometer.

Fig. 48 shows one of the different forms of vibration magnetometer employed in the laboratory. It consists of a hollow rectangular box *B*, of which the two longitudinal sides are made of glass. A cylindrical glass tube *G* having a torsion head *T* at the top is fixed to the middle of the top surface of the box. An unspun silk fibre is suspended from the torsion head and a cradle is attached to the lower end of this fibre. The cradle hangs at the middle of the box and at a small distance above the inside surface of the base. A magnet *NS* can be made to oscillate on a horizontal plane by placing it on the cradle in such a way that (*i*) the upper face of magnet is horizontal, that (*ii*) the axis of its rotation, which coincides with the vertical suspension fibre, may pass through the c.g. of the magnet and (*iii*) that there is no pendulum oscillation of the suspension fibre. A rectagular strip of mirror *R*, having a longitudinal line *MM*

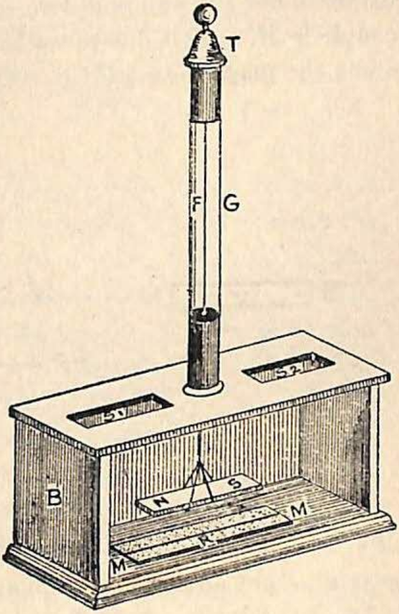


Fig. 48

marked on it, is fixed on the inside surface of the base of the box with the length of the mirror parallel to the length of the boxs. This line on the mirror helps us to find the time of transit of the magnet accurately in course of its oscillations. This line and also the oscillation of the magnet can be seen from above the box by looking vertically downwards through two rectangular slots S_1 and S_2 on the top surface of the box.

46. *Determination of the earth's horizontal intensity and the magnetic moment of a magnet by employing magnetometers.*

Theory: In Fig. 49 the magnetic needle (ns) is in equilibrium under the action of two equal and opposite couples. One couple (mH, mH) is due to earth's horizontal field H running along the magnetic meridian, while the other couple (mF, mF) is due to the field F of a magnet (NS) of moment M whose axis is kept at right angles to the magnetic meridian. If θ be the angle of deflection of the needle from the magnetic meridian, it can be shown that,

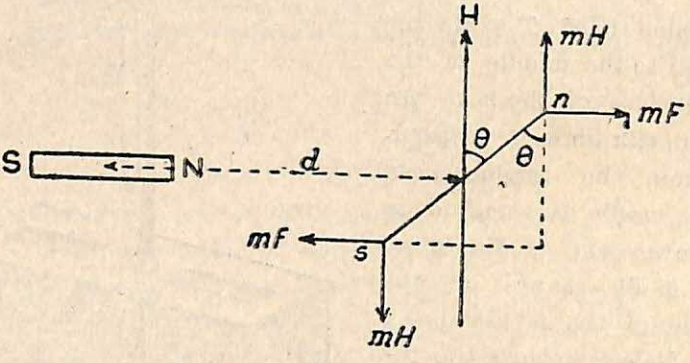


Fig. 49

$$\frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \tan \theta. \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Here d = distance between the centres of the magnet and the needle

and l = half the magnetic length of the magnet.

$$\text{or, } l=\frac{\text{actual length of the magnet}\times{}^{\cdot}85}{2}=\frac{l'\times{}^{\cdot}85}{2}. \quad \ldots \quad (2)$$

If the magnet (NS) be allowed to oscillate with a small amplitude on a horizontal plane under the action of earth's horizontal intensity (H) only, the period of oscillation is given by,

$$T=2\pi\sqrt{\frac{I}{MH}}$$

$$\text{or,} \quad MH=\frac{4\pi^2 I}{T^2}. \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

As the magnet oscillates about a vertical axis passing through its centre of gravity, the moment of inertia (I) of the given magnet of rectangular cross-section is given by

$$I=\frac{\text{Mass}}{12}\left\{(\text{length})^2+(\text{breadth})^2\right\}=\frac{m'}{12}\left(l'^2+b'^2\right). \quad \ldots \quad (4)$$

Finding M/H from (1) and (2) and MH from (3) and (4), we can calculate M or H from (1) and (3) by multiplication or division respectively.

Procedure : (*i*) The mass (m') of the given magnet is determined by a balance, while its length (l') and breadth (b') are determined by a slide callipers when the length l' of the magnet is less than 6 cm., or by a scale when l' is greater than 6 cm. The moment of inertia I of the magnet is then calculated from the relation (4), while half of its magnetic length (l) is determined by using the relation (2).

(*ii*) All magnets and magnetic substances are removed from the working table and the magnetometer is placed on the table with its two arms perpendicular to the magnetic meridian, *i.e.* perpendicular to the magnetic needle (ns). At this time the pointer usually reads (0° – 0°) of the circular scale. But this perpendicular position of the arm is to be further tested by placing the magnet along the arm at a certain distance and observing the deflections of the needle when the N-pole and S-pole of the magnet alternately points the needle. Equal deflections of the needle will indicate the correct position of arms.

(*iii*) The magnet (NS) is now placed on the arm of the magnetometer at the east side of the needle, so that the length of the magnet is parallel to the arm. The position of the magnet on the arm is adjusted until the pointer reads about 45° on the circular scale. The readings d_1 and d_2, corresponding to the two ends of the magnet, are noted from the metre-scale fixed on the arm. The distance of the needle from the centre of the magnet is then given by $d=(d_1+d_2)/2$.

(*iv*) Keeping this distance d of the needle from the centre of the magnet (NS) *constant*, the readings of the two ends of the pointer are noted from the circular scale when, (*a*) the two flat surfaces of the magnet are alternately touching the arm and (*b*) the N-pole and S-pole of the magnet are alternately pointing towards the needle. For each position of the magnet we are getting two readings corresponding to the two ends of the pointer and hence for the four positions of the magnet, as are indicated in (*a*) and (*b*), we shall get altogether eight readings.

(*v*) The magnet (NS) is then transferred to the other arm of the magnetometer at the west side of the magnetic needle so that *the distance of the needle from the centre of the magnet is again* 'd'. The operation (*iv*) is then repeated when we get another set of eight readings. The mean of these 16 readings gives θ from which M/H is calculated by using the relation (1).

(*vi*) The magnet is now placed at two other distances from the needle until the deflections of the pointer on the circular scale are about 43° and 47° respectively. By taking the two scale readings corresponding to the two ends of the magnet, we get the new distance of the needle from the centre of the magnet. Then the entire operations of (*iv*) and (*v*) are repeated and M/H is calculated. The mean of these three values of M/H is found out.

(*vii*) The magnet is then suspended horizontally in the vibration magnetometer box and the box is rotated until the axial line of the magnet is parallel to the horizontal line marked on the plane mirror fixed to the base of the box. The magnet in then deflected by a very small angle with the help of an auxiliary magnet and the time taken for 30 complete oscillations is noted thrice. When the mean time for these three observations is divided by 30, we get the period T. These values of I and T, when put in the equation (3), we get MH. Knowing mean M/H and MH we can calculate M or H.

Experimental data :

(A) *Moment of inertia* (I) *of the magnet* :—

[When the length l' of the magnet is less than 6 cm., write the details of finding the vernier constant of slide callipers (as is given in Expt. 10) which is to be used to find l' and b'].

TABLE I

Mass of the magnet (m')	Length of the magnet in. cm. (l')	Breadth of the magnet in cm. (b')	Moment of inertia of the magnet $I=\frac{m'}{12}(l'^2+b'^2)$	Half the magnetic length of the magnet $=l=\frac{l'\times\cdot85}{2}$
...gm+.. gm.	(*i*)...	(*i*)...		
+...mg+......	(*ii*)...	(*ii*)...	$I=$	
=.. gm.	(*iii*) ..	(*iii*)...	....	$l=$...cm.
	Mean l'	Mean b'	gm.–cm.^{2}	
	=...	=...		

(B) *To find M/H :—*

TABLE II

No. of observations	Mean of the scale readings for the two ends of magnet $d=(d_1+d_2)/2$ cm.	Position of magnet	Deflection of the needle in degrees, when the magnet is								Mean deflection in degrees (θ)	Value of M/H	Mean M/H
			On the East-arm of magnetometer				On the West-arm of magnetometer						
			N-pole pointing the needle		S-pole pointing the needle		N-pole pointing the needle		S-pole pointing the needle				
			End I	End II	End I	End II	End I	End II	End I	End II			
1	$\frac{1}{2}$(… +…)	(a)	45	46	…	…	…	…	…	…	…	…	
	=…	(b)	45	45	…	…	…	…	…	…			
2	$\frac{1}{2}$(… +…)	(a)	43	…	…	…	…	…	…	…	…	…	…
	=…	(b)	…	…	…	…	…	…	…	…			
3	$\frac{1}{2}$(… +…)	(a)	47	…	…	…	…	…	…	…	…	…	
	=…	(b)	…	…	…	…	…	…	…	…			

N.B. [Obs. (a) are for one flat surface of the magnet touching the arm. Obs. (b) are for another flat surface of the magnet touching the arm.]

(C) *Determination of MH :—*

TABLE III

No. of obs.	Times for 30 oscillations	Mean time (t)	Period $T=t/30$ in secs.	M. I of the magnet (I)	$MH=\frac{4\pi^2 I}{T^2}$
1.	…min . sec.				
2.	. min…sec.	…min…sec.	…	.. gm.-cm^2.	…
3.	…min…sec.				

Calculation :

(i) $\frac{M}{H}=\frac{(d^2-l^2)^2\tan\theta}{2d}=$ ... = ...

(ii) $\frac{M}{H}=$ ... = ... = ...

(iii) $\frac{M}{H}=$ ... = ... = ...

(iv) $MH=\frac{4\pi^2 I}{T^2}$ = ... = ...

$H=\sqrt{MH\Big/\frac{M}{H}}=$ ... = ... Oersted.

$M=\sqrt{MH\times\frac{M}{H}}=$ ... dyne-cm. per Oersted.

Precautions : (i) Before starting the experiment, all magnets and irons should be removed at a great distance from the working table.

(ii) The error in the measurement of M/H would be minimum when d is large and θ is 45°, [See p. 5, item (c)]. Hence the deflection should be kept near about 45° and the value of d should be large in comparison with the length of the magnet.

(iii) To bring the two arms of the magnetometer perpendicular to the magnetic meridian (*i.e.* to bring the axis of the magnet perpendicular to the magnetic meridian) the position of the arm is to be adjusted until equal deflections of the needle are obtained with N-pole and S-pole alternately pointing the needle.

(iv) The magnetic needle should be made free, so that a small shift of the magnet may change the deflection of the needle. To minimise the effect of friction the magnetometer box should be tapped a little before taking the reading.

(v) During the oscillation of the magnet the amplitude of its oscillation should be made small (not exceeding 10°) and the *oscillation of the suspension fibre should be avoided*, *i.e.* there should not be any pendulum oscillation of the magnet.

(vi) The magnet should be so placed on the cradle that its upper face is horizontal and the vertical axis of oscillation passes through its centre of gravity. The suspension fibre must be made twist-free.

(*vii*) For calculations of moment of inertia, the length and breadth of that face of the magnet should be measured which was horizontal during oscillation.

Oral Questions and their Answers

1. Define (*a*) pole strength, (*b*) magnetic moment of a magnet, and (c) magnetic intensity,

(*a*) Pole strength of the magnet pole is the force exerted on the pole when it is placed in a uniform magnetic field of unit intensity. (*b*) Magnetic moment of a magnet is the moment of the mechanical couple required to keep it at right angles to a uniform magnetic field of unit intensity or it is measured by the product of any one of the two pole strengths of the magnet and its magnetic length. (*c*) Magnetic intensity at a point is the force exerted on unit *N*-pole placed at that point.

2. What is the magnetic length and how is it related to the actual length ?

The distance between the two poles of a magnet is called the magnetic length and it is approximately ·85 times the actual length.

3. What are magnetic elements ? Are they constant at all places ?

Dip, declination and horizontal intensity are called magnetic elements, for the knowledge of these three quantities given complete picture of the earth's magnetic field. The values of the magnetic elements are different at different places.

4. How does the earth's magnetic field run ? What is the horizontal intensity ?

Earth's magnetic field is running from south to north along a vertical plane called the magnetic meridian which is inclined with the geographical meridian by a certain angle known as Declination. Again the total field (I) is running along the magnetic meridian by making a certain angle θ with the horizontal and this angle θ is called the Inclination or Dip at the place. The componont ($I\cos\theta$) of earth's total field (I) along the horizontal is called the Horizontal intensity (H).

5. What are Tangent A and B positions of Gauss ?

When the magnetic axis of the deflecting magnet is kept at right angles to the magnetic meridian. There are two distinct positions of the deflected magnetic needle. In A-positions the magnetic needle is placed on the axial line while in B-position, the magnetic needle is placed on the equatorial line of the deflecting magnet.

6. Can you perform your experiment by placing the axis, of the deflecting magnet along the magnetic meridian ?

No : in that case the earth's field and the magnet's field become parallel and there is no deflecting couple on the magnetic needle.

7. Why do you keep one of the dflections of the needle at 45° ?

In that case, the error in the measurement of M/H would be minim um [see p. 5, in item (*c*)]

8. Why do you record the deflections of the needle when (*a*) the *N*-pole and the *S*-pole of the deflecting magnet are alternately pointed towards the needle ; (*b*) a particular face of the magnet is kept alternately up and down ; (*c*) the deflecting magnet is kept alternately at equal distances on the two arms of the magnetometer, situated on the opposite sides of the needle ?

(*a*) To eliminate the error, resulting from the axis of the magnet not being perpendicular to the magnetic meridian as well as to eliminate the effect of non-uniform distribution of magnetism at the two ends of the magnet ; (*b*) to correct the error arising out of the non-coincidence of magnetic and geometric axis of the magnet ; (*c*) to eliminate the error which may come, if the zeros of the two scales, fixed on the two arms of the magnetometer, do not coincide with the centre of the needle.

9. Why do you note the readings at the two ends of the pointer ?

To eliminate the eccentric error, *i.e.* the error, arising out of the non-coincidence of the centre of the needle with that of the circular scale.

10. Define Period and Amplitude of vibration [see items (*iii*) and (*v*) of Art. 37].

11. Define moment of inertia and radius of gyration [see oral question no. 1 of Expt. 20].

12. Can you find the pole strength of the deflecting magnet by this experiment ?

Yes ; by finding the magnetic moment M by this experiment the value of pole strength m can be obtained by dividing M with the magnetic length ($2l$) of the magnet.

13. Will the values of M/H and MH obtained by you, remain the same when you perform your experiment at another part of the world ?

No ; the variation of H, at different places on the earth's surface, will cause a variation of the values of M/H and MH.

47. Verification of the law of inverse square in magnetism by using deflection magnetometer.

Apparatus: Apparatus required for this purpose is a deflection magnetometer as shown in Fig. 47.

Theory: If the intensity of field due to a magnet pole is assumed to vary inversely as the *n*th power of the distance, then it can be shown that the intensity of the field at a distance *d* from the centre (*O*) of a short magnet (*NS*) of magnetic momet *M* would be [Figs. 50 and 51],

$$F_A = \frac{Mn}{d^{n+1}} \text{ [along the axial line of the magnet]} \quad \cdots \quad (1)$$

$$F_B = \frac{M}{d^{n+1}} \text{ [along the equatorial line of the magnet]} \quad \cdots \quad (2)$$

$$\therefore \quad \frac{F_A}{F_B} = n \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad (3)$$

If a short magnetic needle (*ns*), placed at a distance *d* from the centre *O* of a magnet *NS*, be in equilibrium under the joint action of earth's horizontal field *H* and the field due to the short magnet *NS* of moment *M*, whose axis is perpendicular to the magnetic meridian (along which earth's field *H* is running) then by equating the two couples acting on (*ns*) we may write,

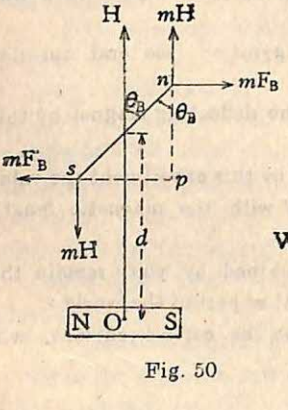
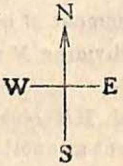


Fig. 50



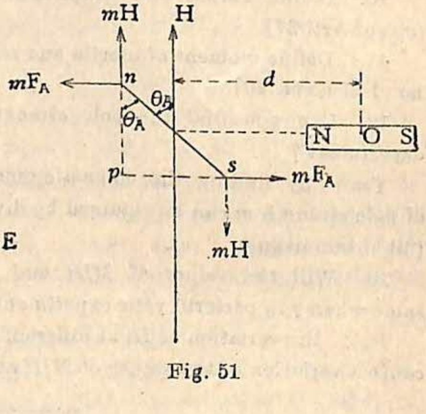


Fig. 51

from Fig. 50 where the needle (*ns*) is on the equatorial line of the magnet *NS*,

$$mF_B\,(np) = mH(sp)\ ;\ \text{or, } F_B = H\,\frac{sp}{np} = H \tan\theta_B \quad \cdots \quad (4)$$

and from Fig. 51, where the needle (*ns*) is on the axial line of the magnet *NS*,

$$mF_A\,(np) = mH(sp)\ ;\ \text{or, } F_A = H\,\frac{sp}{np} = H \tan\theta_A \quad \cdots \quad (5)$$

Taking the ratio of (5) and (4) we get,

$$\frac{F_A}{F_B} = \frac{\tan\theta_A}{\tan\theta_B} \quad \cdots \quad \cdots \quad \cdots \quad (6)$$

From (3) and (6) we get, $\frac{\tan\theta_A}{\tan\theta_B} = n \quad \cdots \quad \cdots \quad (7)$

If by experiment, the value of n is found to be 2, then the law of inverse square would be verified.

Procedure :

Tan A-position :—(*i*) Removing all magnets and magnetic substances from the working table, the two arms of the magnetometer are brought *perpendicular to the magnetic meridian i.e.* perpendicular to the needle (*ns*). At this time the pointer usually reads (0° – 0°) of the circular scale.

(*ii*) The magnet *NS* is now placed on one arm of the magnetometer, so that the *length of the magnet is parallel to the arm* (see Fig. 47). The position of the magnet on the arm is now adjusted until we get a certain deflection of the pointer (say about 45°). The reading (*d*) corresponding to the *centre O of the magnet* (*NS*) is noted from the scale attached to the arm.

(*iii*) Keeping this distance *d* of the needle from the centre of the magnet (*NS*) constant, the deflections of the two ends of the pointer are noted for one position of the magnet *NS* on the arm and then for its another position obtained by rotating it by 180°, so that the positions of N-pole and S-pole of the magnet are interchanged. For each position of the magnet, the deflections of the two ends of the pointer are noted, when the two flat surfaces of the magnet NS are made to touch the arm of the magnetometer alternately. From these observations we get altogether eight angles of deflections of the pointer.

(*iv*) The magnet NS is then transferred to the other arm of the magnetometer, so that the distance of the needle from the centre of the magnet (NS) is again d. The operation (*iii*) is then repeated when we get another eight angles of deflection of the pointer. The mean of these 16 deflections of the pointer gives θ_A.

(*v*) The distance of the needle from the centre of the magnet NS is now successively increased to d' and d'' until the deflections of the pointer decreases by about 2° (say of the order of 43° and 41° respectively). For each distance of the magnet NS, the operations (*iii*) and (*iv*) are repeated and in each case the mean deflections θ_A' and θ_A'' are obtained.

Tan B-position :—(*i*) The two arms of the magnetometer are now brought *along the magnetic meridian i.e.* parallel to the needle (ns). At this time the pointer usually reads (90° – 90°) of the circular scale.

(*ii*) The magnet NS is now placed on one arm of the magnetometer, so that the *length of the magnet is perpendicular to the arm.* The position of the magnet NS on the arm is adjusted until the reading of the metre scale on the arm corresponding to the *centre of the magnet* is again d as in the operation (*ii*) of Tan A-position.

(*iii*) to (*v*) The operations (*iii*) to (*v*) in Tan A-position are to be repeated for the *same three positions, viz.* d, d' and d'' of the magnet and in each case the mean of the 16 deflections θ_B,

θ_B' and θ_B'' (which will not be of the same order as in Tan *A*-position) are to be found out.

(*vi*) We shall find that, $\frac{\tan \theta_A}{\tan \theta_B} = \frac{\tan \theta_A'}{\tan \theta_B'} = \frac{\tan \theta_A''}{\tan \theta_B''} = 2.$

This verifies the inverse square law in magnetism.

TABLE I

Experimental data :

(A) *Distance—deflection records* :—

Position of the magnet	No. of observations	Distance between the centres of magnet and needle in cm.	Deflections in degrees of the needle when the magnet is,								Mean deflection in degree	Ratio of the tangents of two deflections for two positions of magnet
			On one arm of magnetometer				On another arm of magnetometer					
			N-pole in one direction		N-pole in the opp. direction		N-pole in one direction		N-pole in the opp. direction			
			End I	End II	End I	End II	End I	End II	End I	End II		
Tan A position	1	...	(*a*)...	...	...	...	...	...	...	...	...	$\frac{\tan \theta_A}{\tan \theta_B}$ =...
		$= d$	(*b*)...	...	...	....	...	...	...	...	$= \theta_A$	
	2	...	(*a*)....	....	...	...	...	...	....	...	...	$\frac{\tan \theta'_A}{\tan \theta'_B}$ =...
		$= d'$	(*b*)...	...	...	...	...	...	...	...	$= \theta_A'$	
	3	...	(*a*)...	...	...	...	...	...	...	...	...	$\frac{\tan \theta''_A}{\tan \theta''_B}$ =...
		$= d''$	(*b*)...	...	...	...	...	...	...	...	$= \theta_A''$	
Tan B position	1	...	(*a*)								...	
		$= d$	*b*								$= \theta_B$	
	2	...	(*a*)								...	
		$= d'$	(*b*)								$= \theta_B'$	
	3	...	(*a*)								...	
		$= d''$	(*b*)								$= \theta_B''$	

N. B. [Obs. (a) are for one flat surface of magnet touching the arm.
Obs. (b) ,, ,, another ,, ,, ,,

Conclusion : As the ratio of the tangents of the two deflections of the needle obtained for Tan A-position and tan B-position becomes equal to 2 in each of the three different cases, we conclude that the inverse square law is true.

Precautions : (*i*) and (*ii*)—[Same as the precautions (*i*) and (*iii*) of Expt. 46].

Oral Questions and their Answers

[Same as the questions and answers given at the end of Expt. 46].

48. Determination of dip at a place by using dip circle.

Construction of Dip circle : It consists of a long magnetic needle *NS* capable of rotation about a horizontal axis which passes (approximately) through the centre of gravity and at right angles to the length of the needle [Fig. 52]. The two ends of the axis rest on two agate knife-edges so that the needle may rotate with as little friction as possible. A vertical circular scale is fixed by the side of the needle and this scale is graduated in four quadrants from 0° to 90° so that (0° – 0°) line is horizontal while (90° – 90°) line is vertical. By this scale the positions of the two ends of the needle can be recorded. The whole structure, in which the needle *NS* and the vertical scale are fixed can be rotated about a vertical axis and this angle of rotation can be recorded by a vernier which moves with the structure on a horizontal scale marked on the base *A* and graduated from 0° to 360°. There are three levelling screws underneath

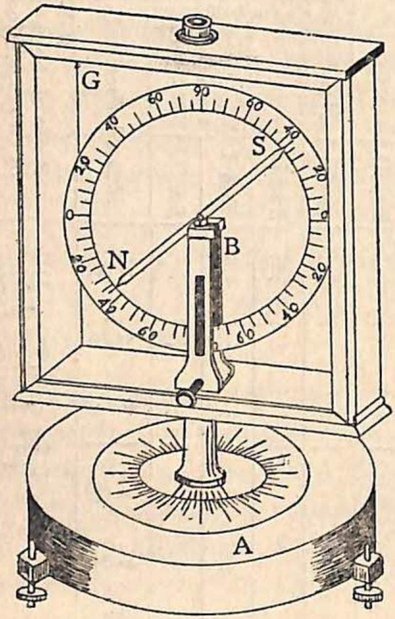


Fig. 52

the base by which the base of the instrument can be levelled with the help of a spirit level fixed at the top of the base.

Theory : The inclination or dip at a place will be the angle which the magnetic axis of the needle, capable of rotating freely about its centre of gravity in the vertical plane of magnetic meridian, makes with the horizontal.

To set the vertical plane of rotation of the needle in the magnetic meridian :—(*i*) The base is made horizontal by the three levelling screws at the base and the spirit level.

(*ii*) The structure is rotated until the upper end of the needle just reads 90° (this time lower end of the needle may not read 90°). The reading of the base scale is noted.

(*iii*) The structure is again rotated a little to make the lower end of the needle just read 90°. The reading of the base scale is again noted.

(*iv*) The needle is now reversed in its bearings and again the operation (*ii*) and (*iii*) are repeated. Thus we get four readings of the base scale. Let the mean of these four readings be θ.

(*v*) The structure *i.e.* the vertical frame containing the needle is now rotated by 180° and the operations (*ii*) to (*iv*) are repeated, when we get another four readings of the base scale. Let the mean of these four readings be θ'. [This θ' will differ from θ by about 180° for the base scale is graduated from 0° to 360°].

(*vi*) Now the mean of θ and θ' is taken *i.e.* $\phi^\circ = (\theta + \theta')/2$ is found out. The vertical frame is now rotated so that the zero of the vernier of the base scale may coincide with the reading ϕ° of the base scale. This time, the vertical plane of rotation of the needle will coincide with magnetic meridian.

Measurement of dip :—(*i*) One face of the needle (NS) is anyhow marked, after completing the former adjustment of setting the vertical plane of rotation of the needle, in the magnetic meridian. The marked face is directed towards east and the readings α_1 and α_2 corresponding to the two ends of the needle are noted from the vertical scale by the side of the needle.

(*ii*) The needle is reversed in its bearings and again readings α_3 and α_4 corresponding to the two ends of the needle are noted from the vertical scale. Thus we altogether get four readings and the mean of these four readings say α is found out.

(*iii*) The structure is now rotated by 180° and the operations (*i*) and (*ii*) are repeated, when we get another four readings β_1, β_2, β_3 and β_4. The mean of these four readings are noted. Let this mean reading be β. Then the mean of α and β be found out. Thus we get $\psi_1=(\alpha+\beta)/2$. If the centre of gravity of the needle is not displaced along the axial line of the needle, then ψ_1 would be the dip at the given place.

(*iv*) To correct for any error arising out of the displacement of c.g. along the axial line of the needle, the needle should be demagnetised and again magnetised with the polarities reversed. The entire operations from (*i*) to (*iii*) are to be repeated to get another set of eight readings and let the mean of which be ψ_2. The correct value of dip at the given place would be, $\psi=\dfrac{\psi_1+\psi_2}{2}$.

Experimental data :

(A) *To bring the vertical plane of rotation of needle in the magnetic meridian :—*

TABLE I

Position of the instrument	Readings in degrees of the base scale when the bearing of the needle is,				Mean of four readings in degrees for each position of instrument	Grand mean at which the lower vernier is to be set
	in one position		reversed			
	Upper pole pointing 90°	Lower pole pointing 90°	Upper pole pointing 90°	Lower pole pointing 90°		
(*a*) When the instrument is in one position	$\ldots=\theta_1$	$\ldots=\theta_2$	$\ldots=\theta_3$	$\ldots=\theta_4$	$\ldots=\theta$	$\phi=\dfrac{\theta+\theta'}{2}$
(*b*) When the instrument is rotated by 180°	$\ldots=\theta_1'$	$\ldots=\theta_2'$	$\ldots=\theta_3'$	$\ldots=\theta_4'$	$\ldots=\theta'$	$=(\ldots)$

TABLE II

(B) *Record of the angle of dip* :—

Marked face of needle facing	Reading in degrees of vertical scale corresponding to.		Mean of four readings in degrees	Mean of α and β in degrees	When the needle is remagnetised, the reading in degrees corresponding to,		Mean of four readings in degrees	Mean of γ and δ in degrees	Dip at the given place in degrees
	upper pole	lower pole			upper pole	lower pole			
East	$\ldots = \alpha_1$	$\ldots = \alpha_2$	$(\alpha_1+\alpha_2+\alpha_3+\alpha_4)/4$		$\ldots = \gamma_1$	$\ldots = \gamma_2$	$(\gamma_1+\gamma_2+\gamma_3+\gamma_4)/4$		$\psi = \frac{\psi_1+\psi_2}{2}$ $= \ldots$
West (reversed in bearing)	$\ldots = \alpha_3$	$\ldots = \alpha_4$	$= \ldots (\alpha)$		$\ldots = \gamma_3$	$\ldots = \gamma_4$	$= \ldots (\gamma)$		
Instrument rotated by 180°				$\psi_1 = (\alpha+\beta)/2$ $= \ldots$	Instrument rotated by 180°			$\psi_2 = (\gamma+\delta)/2$ $= \ldots$	
East	$\ldots = \beta_1$	$\ldots = \beta_2$	$(\beta_1+\beta_2+\beta_3+\beta_4)/4$		$\ldots = \delta_1$	$\ldots = \delta_2$	$(\delta_1+\delta_2+\delta_3+\delta_4)/4 =$		
West (reversed in bearing)	$\ldots = \beta_3$	$\ldots = \beta_4$	$= \ldots (\beta)$		$\ldots = \delta_3$	$\ldots = \delta_4$	$\ldots (\delta)$		

Precautions : (*i*) The levelling of the instrument should be made to make (1) the base horizontal, (2) the plane of rotation of the needle vertical and (3) to avoid any obstruction of the needle during its rotation.

(*ii*) All magnets and magnetic substances should be removed from the working table during experiment.

(*iii*) Parallax should be avoided in taking the readings.

Oral Questions and their Answers

1. Define dip at a place.—See theory.

2. What are magnetic elements ? Are they constant at all places ?
[See the answer of Q. 3, Expt. 46].

3. How does the earth's magnetic field run ? What is the horizontal intensity ? [See the answer of Q. 4, of Expt. 46].

4. What pole of the needle will dip in Northern and Southern hemisphere ?

North pole and south pole of the needle respectively.

5. Why do you take the readings at the two ends of the needle and reverse the needle in its bearings ?

To avoid eccentric error, the readings of the two ends of the needle are noted. The needle is reversed in its bearings to correct the errors arising out of the (*i*) displacement of the c.g. of the needle away from the axial line and (*ii*) non-coincidence of the magnetic axis with the geometric axis of the needle.

6. Why the readings are taken by rotating the instrument by 180° ?

To eliminate the error due to non-horizontality of (0—0) line of the vertical scale.

7. Why is it necessary to demagnetise the needle and remagnetise it with reversed polarity ?

To eliminate the error, if any, due to the displacement of the c.g. of the needle away from its axis along the axial line.

8. What are isoclinic and aclinic lines ?

On the map of the world, lines are drawn by joining places having equal inclination and zero inclination. The former line is called isoclinic line while the latter line is called aclinic line.

9. Are the magnetic elements constants at a given place ?—No ; they are subject to slow irregular variation. Sudden variation of the magnetic elements is known as magnetic storms.

10. If an iron is suspended exactly from its c.g. before and after magnetisation then, what will you observe ?

The iron will remain horizontal before magnetisation but it will remain inclined to the horizontal after magnetisation.

APPENDIX A

*GLASS BLOWING

1. *Accessories for glass blowing.*

(i) Glass : Though hard glass, such as Pyrex, is extensively employed for the construction of laboratory apparatus, soft glass is very helpful for elementary purposes, since it has a lower working temperature than hard glass. For annealing purposes hard glas is, however, advantageous over soft glass because of its low thermal expansion and high strength. Some physical properties of different types of glass are given below :

Material	Strain point	Annealing temp.	Working temp.	Coefficient of linear expansion × 10^7
Soft glass	389°C	425°C	...	...
Lime ,,	...	...	...	92
Lead ,,	....	...	...	90
Quartz	1020°C	1120°C	1756°C to 1800°C	5 8
Pyrex	503°C	550°C	750°C to 1100°C	32

(ii) Flame : Cross-fires (Fig. 3) are employed for heating glass to softness over a considerable length. By this method of heating, glass is heated more rapidly and uniformly. Another method of heating is by the single blast burner. By this method we cannot get rapid and uniform heating as that obtained by cross-fires. Sometime we require a pointed flame which can be more easily obtained with a blast burner. For low temperature work in the laboratory with soft glass, fish-tail burner may be employed.

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*For details, consult '*Modern Physical Laboratory Practice*' —*by John Strong.*

(iii) Fuel for the burner : For ordinary laboratory work with soft glass, coal gas mixed with compressed air (such as in blow pipe flame) is used. For high temperature work with hard glass, acetylene mixed with compressed air or oxygen may be employed as a fuel.

(iv) Other acccssories : The other articles which are often required for glass blowing are, a working table covered with an asbestos sheet (the table should be high enough for the operator to rest his elbows on), some corks of various sizes (some of them are fitted with closed glass tubes which serve as handles for rotating the work, while others are fitted with open tubes for blowing), blowing arrangements (such as foot-blower or Swivel '*L*' hose and mouth piece), forceps, sharp files of different sizes for cutting glass, etc.

2. *Operation in glass blowing.*

A person performing experiments in the laboratory, often feels the necessity of knowing the technique of glass blowing. The fundamental operations, which are involved in glass blowing, are explained below.

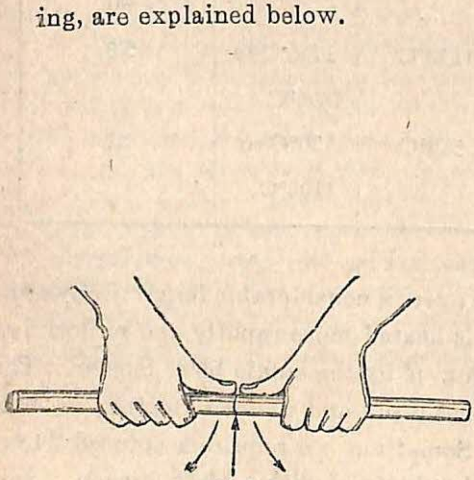

Fig. 1

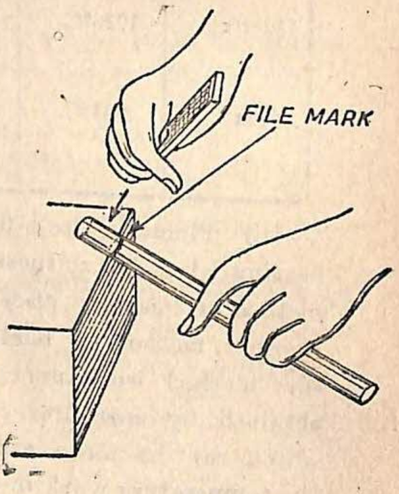

Fig. 2

(*a*) Cutting the tubes : To cut a tube (not more than ½ an inch in diameter) a scratch mark of a few millimetre long is made *accurately perpendicular* to the tube with the sharp edge of a file. A break is then made by a combined bending and pulling force as illustrated in Fig 1.

If the tube is hot or if it is to be cut near one end, it can be broken at the scratch mark by a stroke with the file as shown in Fig. 2.

(b) Cleaning : The next operation after cutting should be the cleaning of the tube. Sometimes washing with tap-water and then drying by blowing air in the tube will serve the purpose. But in more accurate experiments, where the presence of a small amount of grease or impurity is harmful, first the bore of the tube should be cleaned by drawing a clean cotton pad in it several times by a wire loop, and then it should be washed with dil. nitric acid, then with strong caustic soda solution and finally in a stream of tap-water. The tube is then to be dried in alcohol or ether or by blowing hot air through it.

(c) Pre-heating : Before exposing the tube to the sudden and intense local heat of blast burner or of the cross-fire, its temperature should be gradually raised in order that it may not crack. For this purpose, the tube should be first heated in the flame *without any air blast.* When the tube has become sufficiently hot, it will now be safe to blow air blast in the burner in order to raise its temperature higher. Under this intense heat of the blast burner, the temperature of the tube becomes very high and it distills sodium vapour to make the flame yellow. This sodium test usually indicates the temperature at which it is safe to begin operations of shrinking, blowing, moulding etc.

(d) Rotation of the work : The rotation of the tube during heating should be done uniformly with perfect co-ordination of two hands as shown in Fig. 3. Glass properly rotated in the flame becomes uniformly soft and the effect of gravity on it is symmetrical.

Due to convection currents of air, the lower surface of hot glass cools more rapidly than its upper surface. Hence the uniform rotation of the tube should be continued even after the work is taken out of the flame. A beginner may find difficulty in the rotation work and to overcome this difficulty he may practice rotation by employing the model explained below.

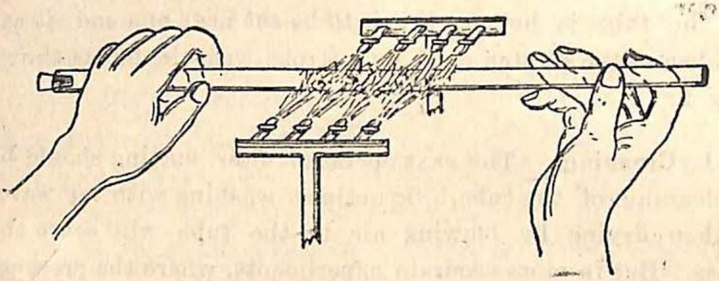

Fig. 3

The model consists of two glass tubes connected with a heavy cloth. He should practise its rotation by employing the two hands in such a way that the cloth may not wrinkle or twist and there is neither compression nor tension. At this stage the person becomes fit to begin operations with the flame.

The hand should be held in the manner as shown in Fig. 3. The left hand manipulates heavier section of glass, while the right hand rotates its other section without stretching or compression relative to the main section of the work.

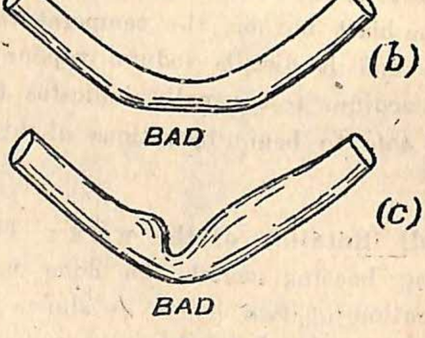

Fig. 4

(e) Bending of tubes: The tube to be bent is heated over a considerable length by a cross-flame with continuous rotation until the heated portion is quite soft. It is then removed from the flame and bent to the desired angle with the convex side downwards as shown in Fig. 4.

Imperfections may arise in bending large tubes and small thin-walled tubes. If the outside flattens [Fig. 4(*b*)], it can be corrected by blowing while the glass is soft. If the inside surface folds [Fig. 4(*c*)] then it is locally heated with a pointed flame and worked by alternately shrinking with blowing until it is uniform.

(f) Shrinking: At an elevated temperature the glass becomes soft and due to the effect of surface tension its surface tends to decrease, thereby producing a deformation. This is known as *shrinking*. The viscosity of glass tends to prevent this shrinking. In the construction of apparatus, shrinking is controlled by the spinning tools and by blowing into the work.

(g) Annealing: When the glass is quickly cooled to room temperature from its working temperature, it breaks due to strain in it. Hence it should be cooled by introducing a minimum amount of strain. For this purpose the glass should be cooled slowly from its working temperature to the room temperature by employing suitably regulated oven.

(h) Blowing bulbs: The blowing of bulbs can be successfully done by (*i*) heating the heavy mass of soft glass to a uniform temperature in the flame and by (*ii*) skilfully managing the air cooling when brought outside the flame, so that the cooling may be symmetrical.

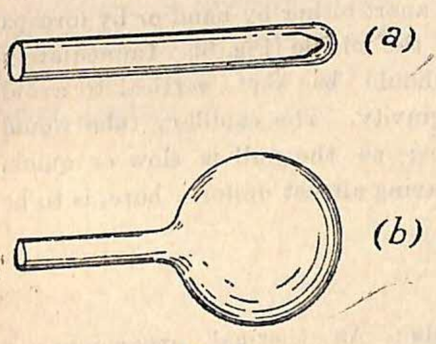

Fig. 5

The first operation is to heat the end of the glass tube until the glass collects at the end [Fig. 5(*a*)]. As the glass collects at the end, it is alternately blown out and shrunk to distribute it uniformly until enough has collected for the final bulb. The collected glass is then heated to a uniform temperature and removed from the flame. After rotating the work for a few seconds about a horizontal axis it is expanded by blowing. The blowing should be gentle at first ; but it should be stronger as the glass stiffens. The work is to be kept in rotation continuously.

If one portion of the surface tends to expand more than the other, that portion should be turned down and cooled so as to restrain its expansion, for the underside cools more rapidly than the other portion.

(i) Drawing of Capillary tubes : A soft glass tube, about 6 to 8 inches long and $\frac{1}{4}$ inch in diameter, is to be taken. A considerable length of it in the middle region should be heated uniformly in cross-fires by rotating the tube continuously. When the heated portions have become soft, the two ends should be pulled apart either by hand or by forceps to form a capillary tube at the middle (Fig. 6). Immediately after drawing, the tube should be kept vertical to avoid bending by the action of gravity. The capillary tube would be wide or narrow according as the pull is slow or quick. A portion of this capillary, having almost uniform bore, is to be cut out.

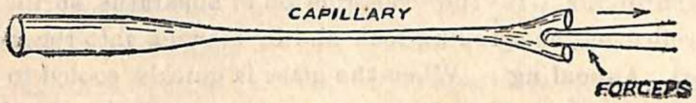

Fig. 6

3. Metal glass seals.

(a) Platinum-glass seals : As thermal expansions of soft glass and platinum are nearly equal, formerly platinum was sealed in glass without getting any crack during cooling. Such seals are rarely used now because of the high price of platinum.

(b) Tungsten-glass seal : Tungsten wires of diameters less than ·06 inch may be sealed through Pyrex. Larger tungsten wires are first sealed in a sleeve of Nonex glass, which in its turn is sealed into the glass. This procedure is helpful, for the total expansion of nonex between its strain point and room temperature is almost equal to the expansion of tungsten. For sealing a tungsten wire, it should be first cleaned and heated to white heat in the gas flame. When sealed in vacuum tubes, the tip of tungsten wires should be closed by fusing nickel. Otherwise air will leak through the fibrous structure of the wire.

(c) Copper-glass seal : It is possible to seal copper to pyrex or soft glass by the technique developed by W. G. House Keeper. The copper has a larger coefficient of expansion than either type of glass. When the copper is thin, it is deformed to absorb differences betwen its expansion and that of glass, a circumstance made possible by its high ductility and low yield point.

(d) Kover and Fernico : The thermal expansion of most metals are almost linear, while the rate of expansion of glasses increases near their softening temperature. The two new alloys Kover and Fernico closely duplicate the expnnsion of some of the commercial glasses. These alloys yield metal-to-glass seals which remain unstrained under all the annealing conditions. Such seals have made modern all-metals radio tubes possible.

APPENDIX B

TABLE OF PHYSICAL CONSTANTS

(General Physics, Heat, Sound and Magnetism)

1. Some important formulae :

Circumference of a circle $= 2\pi r$

Area of circle $= \pi r^2$

Surface area of a sphere $= 4\pi r^2$

Volume of a sphere $= \frac{4}{3}\pi r^3$

Curved surface of a cylinder $= 2\pi r \times \text{length}$

Volume of a cylinder $= \pi r^2 \times \text{length}$

2. Moment of inertia of some regular bodies :

Body	Axis of rotation	Moment of Inertia
Rectangular lamina	Passes perpendicular to the surface and through the C. G. of the lamina	$\frac{M}{12}\left(l^2+b^2\right)$
Cylinder	Coincides with that of the cylinder	$\frac{1}{2}Mr^2$
,,	Passes perpendicular to its length and through the C.G.	$M\left(\frac{l^2}{12}+\frac{r^2}{4}\right)$
Sphere	Coincides with any diameter	$\frac{2}{5}Mr^2$

3. Conversion table :

Length	Mass	Volume
1 inch = 2·54 cm.	1 lb. = 453·6 gms.	1 gallon = 4·54 litres.
1 metre = 39·37 inches	1 gm. = 15·43 grains	1 cu. ft. = 28·311 litres.
1 mile = 1·609 kilometre	1 kg. = 2·2 lbs.	1 pint = ·568 litres.

4. Density of common substances.

Substance	Density in gms./c.c.	Substance	Density in gms./c.c.	Substance	Density in gms./c.c.
Solid .		Paraffin	·87—·93	Mercury	13·6
Aluminium	2·7	Common salt	2·17	Milk	1·03
Alum	1·76			Paraffin oil	·8
Brass	8·4—8·7	Sand	2·63	Petrol	·68—·7
Copper	8·93	Sugar	1·59	Sulphuric acid	1·84
Cork	·22—·26	Wood	·7—·9	Turpentine	·87
Glass (crown)	2·5—2·7			Water (pure)	1·00
,, (flint)	2·9—4·5	**Liquids :**		,, (sea)	1·026
Iron (cast)	7—7·7	Alcohol	·792	Gases at N.T.P.	
,, (wrought)	7·8—7·9	Glycerine	1·26		
,, (steel)	7·7—7·9	Kerosine	·80	Hydrogen	·000089
Marble	2·5—2·8	Methylated spirit	·83	Air	·001293

5. Variation of density of water with temperature.

Temp. in °C.	0	2	4	6	8
0	·99987	·99997	1·0000	·99997	·99988
10	·99973	·99953	·99927	·99897	·99862
20	·99823	·99780	·99732	·99681	·99626
30	·99567	·99505	·99440	·99371	·99300
40	·99220	·99150	·99070	·98980	·98900
50	·9881	·9872	·9862	·9853	·9843

6. Elasticities and Breaking stresses of materials.

Material	Young's modulus in dynes per sq. cm. (Y)	Rigidity in dynes per sq. cm. (n)	Breaking stress in kilos per sq. cm.
Brass	$9{\cdot}7-10{\cdot}3\times10^{11}$	$3{\cdot}5\times10^{11}$	3400
Copper	$12{\cdot}4-12{\cdot}9$,,	$3{\cdot}9-4$,,	3000
Iron (wrought)	$19-20$,,	$7{\cdot}7-8{\cdot}3$,,	6000
Steel (ordinary)	$19{\cdot}5-20{\cdot}6$,,	$7{\cdot}9-8{\cdot}9$,,	11230

7. Surface tensions of liquids in contact with air.

Substance	Temperature in °C	Surface tension in dynes/cm.	Substance	Temperature in °C	Surface tension in dynes/cm.
Water	0	76·5	Glycerine	20	63·14
,,	20	73·5	Olive oil	20	32
,,	30	72	Paraffin oil	25	26·4
Ethyl alcohol	20	21·7	Turpentine	15	27·3

8. Viscosities of liquids and gases.

Substance	Temperature in °C	Viscosity in c.g.s. unit	Substance	Temperature in °C	Viscosity in c.g.s. unit
Water	0	·01793	Ethyl alcohol	30	·00989
,,	15	·01142	Paraffin oil	19	·02
,,	20	·01006	Olive oil	15	·99
,,	25	·00893	Air	0	·000113
,,	30	·00800	Water vapour	0	·000087

9. Coefficient of expansion of substances.

Substance (solids)	Coefficient of linear expansion per °C	Substance (liquids)	Coefficient of cubical expansion per °C (real expansion)
Aluminium	25·5 $\times 10^{-6}$	Alcohol (Ethyl)	110 $\times 10^{-5}$
Brass	18·9 ,,	Benzene	124 ,,
Copper	16·7 ,,	Glycerine	53 ,,
Glass (crown)	9 ,,	Mercury	18·18 ,,
Iron (cast)	10·2 ,,	Paraffin oil	90 ,,
,, (wrought)	11·9 ,,	Turpentine	94 ,,
German Silver	18·4 ,,	Water(20° – 40°)	30·2 ,,
		Air	367 ,,

10. Specific heats of solids and liquids.

Substance	Specific heat	Substance	Specific heat	Substance	Specific heat
Solid :					
Aluminium	·21	Marble	·21 – ·22	Glycerine	·58
Brass	·089	Common salt	·21	Castor oil	·508
Copper	·091	Nickel	·106	Linseed oil	·44
German Silver	·095	Paraffin wax	·69	Olive oil	·47
Glass (crown)	·16	Procelain	·18	Paraffin oil	·51 – ·54
,, (flint)	·12	Sand	·19	Mercury	·034
Iron	·105	**Liquid :**			
Ice	·502				
Lead	·03	Alcohol	·547	Turpentine	·42

11. Pressure of saturated water vaponr.

Temp. in °C	Pressure in mm. of *Hg*	Temp. in °C.	Pressure in mm. of *Hg*	Temp. in °C.	Pressure in mm. of *Hg*	Temp. in °C.	Pressure in mm. of *Hg*
15	12·779	22	19·79	29	29·94	36	44·40
16	13·624	23	21·02	30	31·71	37	46·90
17	14·517	24	22·32	31	33·57	38	49·51
18	15·460	25	23·69	32	35·53	39	52·26
19	16·456	26	25·13	33	37·59	40	55·13
20	17·51	27	26·65	34	39·75	45	71·64
21	18·62	28	28·25	35	42·02	50	92·30

12. Mechanical equivalent of heat (J).

$J = 4{\cdot}185 \times 10^7$ ergs per calorie

$= 4{\cdot}185$ Joules per calorie.

$J = 778$ foot-lbs./B. Th.U.

13. Thermal conductivity (in cal. per cm. per sec. per °C) of solids.

Substance	Thermal conductivity,	Substance	Thermal conductivity	Substance	Thermal conductivity	Substance	Thermal conductivity
Aluminium	·480	Copper	·918	Glass (crown)	·0025	Lead	·08
Brass	·260	German silver	·070	Glass (flint)	·002	Steel	·11

14. Melting and Boiling points of substances.

Substance	Melting point in °C	Substance	Boiling point in °C	Substance	Boiling point in °C
Solid :		Liquid :		Chloroform	61·2
Bees wax	61 – 64	Alcohol (ethyl)	78·3	Ether	34·6
Naphthaline	80	Aniline	183·9	Glycerine	290
Paraffin (hard)	52 – 56	Benzene	80·2	Phenol	181·5
Palmitic acid	62·6	Carbon di-sulphide	46·2	Stearic acid	291
Phenol	42·7	Carbon tetra chloride	76·7	Turpentine	159
Stearic acid	69·3			Xylene	142·6

15. Velocity of sound in several media.

Media	Velocity in metres per sec.	Media	Velocity in metres per sec.	Media	Velocity in metres per sec.
Air at °*C*	$332 + {\cdot}61t$	Glass	5000	Mercury	1407
Brass	3400	Hydrogen	1362	Nitrogen	338
Copper	3600	Iron	5130	Water at t°C	$1390 + 3{\cdot}3t$

16. Magnetic elemets and g.

Place	Declination	Dip	Horizontal intensity in Oersted	g in cm./sec^2.
Agra	10′ E	40°41′ N	·348	979
Allahabad	20′ E	37°10′ N	·363	978·94
Bombay	41′ E	24°21′ N	·365	978·6
Calcutta	33′ E	30°59′ N	·373	978·8
Delhi	2°2′ E	40°56′ N	·340	979·2
Madras	0°10′ W	34°37′ N	·369	978·3

A TEXT BOOK ON

PRACTICAL PHYSICS

[For Three-year Degree Course (Pass)]

PART II

[Light and Electricity]

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CHAPTER I

LIGHT

1. An Optical bench and its uses.

Description : Measurements of the optical constants of mirrors and lenses are best performed by using optical bench. Fig. 1 shows one of the various forms of optical bench which are employed. The object, the lens, and the screen are mounted on stands bearing an index or reference mark. The stands can slide along the bench so that the reference mark always touches a scale graduated in mm. As these reference or index marks are not properly placed, a correction known as *index correction* is always necessary.

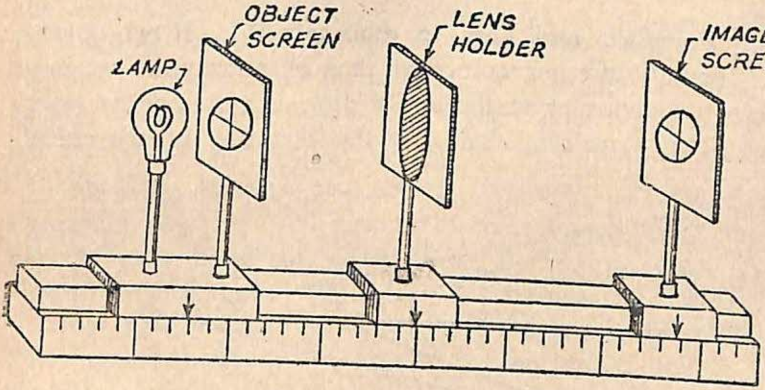

Fig. 1

On the object-screen, there is a hole provided with a cross-wire. This cross-wire, which is illuminated by an electric lamp, serves the purpose of the object. The image-screen is nothing but a white paper or a ground glass fixed to a frame. The lens can be placed in a lens holder kept on the stand placed between the object and the screen.

Index correction : To correct for the index error which may exist between the object-screen and the lens, or between the image-screen and the lens, or between the object-screen and the image-screen, the following procedure is adopted. The length l (l is about 30 cm.) of an iron or glass rod with pointed ends is measured accurately by a scale. The stands carrying the two things, between which index error is to be corrected, are brought nearer and they are made to touch the two pointed ends of the rod. At this time, the readings R_1 and R_2 of the bench scale corresponding to the index or reference marks of the two stands are noted. Let the difference of these two readings, viz., $(R_1 \sim R_2)$ be d. Then the index error between the two stands is $(l-d)$. If the distances are to be measured from the centre of an equi-convex lens, then the index error would be $(l-d+t/2)$, where t is the thickness of the middle region of the lens. This quantity, viz., $(l-d)$ or $(l-d+t/2)$ should be *algebraically added* to the quantity which is to be corrected for the index error.

2. Precautions to be taken in optical experiments.

(a) Parallax and how to eliminate it : If two objects (say O_1 and O_2) are not coincident then on moving the eye in a direction perpendicular to the line joining the two objects (viz., the line EO_1O_2) we shall find that the direction of movement of the distant object (O_2) is the same as that of the eye while the direction of movement of the nearer object (O_1) is opposite to that of the eye [Fig. 2]. This phenomenon is known as *Parallax*. When the two objects (viz., O_1 and O_2) coincide there will be no relative movement between them as the eye is

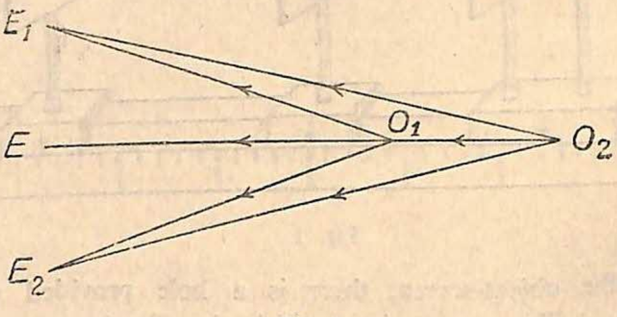

Fig. 2

moved along a line (the line E_1EE_2) which is perpendicular to the line (the line EO_1O_2) obtained by joining the two objects (viz., O_1 and O_2).

It is evident from the Fig. 2 that when the eye is placed at E on the line O_2O_1E, the two rays O_2E and O_1E, from O_2 and O_1 respectively follow the same path and hence the two objects O_2 and O_1 will be found to be coincident.

When the eye is moved towards left in the position E_1, the object O_2 will be seen towards left; for the ray O_2E_1 from the object O_2 remains on the left side of the ray O_1E from the object O_1.

Again when the eye is moved towards right in the position E_2, the object O_2 will be seen towards right; for the ray O_2E_2, from the object O_2 remains on the right side of the ray O_1E_2 from the object O_1.

Thus as the eye moves perpendicular to the line O_2O_1E, *the more distant of the two objects, viz.,* O_2 *moves with the eye while the nearer object viz.,* O_1 *moves opposite to the eye.* By these movements of O_1 and O_2 relative to the movement of eye, we can detect which object (here O_1) is nearer to the eye and which object (here O_2) is far away from the eye.

Hence to make the two objects O_1 and O_2 coincident, either the nearer object O_1 will have to be moved away from the eye *i.e.,* towards the distant object O_2 or the distant object O_2 will have to be moved towards the eye, *i.e.,* towards the nearer object O_1, *until there is no separation between the two objects* O_1 *and* O_2 *whether the eye is moved from E towards* E_1 or E_2. The two objects will be found to move together with the movement of the eye.

Of the two objects, O_1 may be actual object while O_2 may be the image of O_1 or it may be the image of another object and *vice versa*. Again both O_1 and O_2 may be the images of two different objects.

(b) Illumination : Whenever an object is to be illuminated by a source of light, it should be illuminated as strongly as possible. The sources of light which are usually employed for illumination purposes are (*i*) sodium flame, (*ii*) electric lamp, (*iii*) diffused day light.

(*i*) When sodium flame is employed to illuminate an object such as a slit, the *brightest part* of the flame is to be put at a distance of about six inches in front of the slit. By trial, the position of the flame is to be adjusted until the image of the slit is brightest. If necessary, a convex lens may be employed to concentrate as much light on the slit as is possible.

(*ii*) When an electric lamp is employed to illuminate an object (which may be a slit or a rectangular cross etc.) the bulb should be made of frosted glass or the clear glass of the bulb should be covered by a thin white tissue paper so that the *formation of the image of the filament of the lamp may be avoided.* If necessary, here also a convex lens may be employed to concentrate as much light on the object as is possible. The bulb should be placed at a distance of about 5 or 6 inches in front of the object to be illuminated.

(*iii*) When an object is to be seen with the help of a telescope or a microscope or a magnifying glass, the usual procedure is to illuminate the object with diffused day light (sometimes electric lamp is employed for illumination). Hence the object to be seen is to be placed at such a position and at such part of the room, where the illumination by day light is greatest.

Sometimes to increase the illumination, the diffused day light is reflected to the object by a reflecting mirror (as in the case of a high power microscope). In some cases, the object to be seen is placed on a white paper so that the illumination of the object may be greater (as in the case of the determination of refractive index of a liquid by microscope).

(c) Focussing of telescopes and microscopes : Whenever a telescope or microscope is employed to view a distant or near object respectively, the following procedure should be followed :—

(*i*) The cross-wires of the telescope or of the microscope should be first focussed very sharply. For this purpose the telescope or the microscope should be directed towards a bright white wall and by drawing the focussing lens in or out the cross-wires should be sharply focussed.

(*ii*) To focus a distant object by a telescope, it should be directed towards that object and the *eye-piece should be drawn in or out* either by hand or by the rack and pinion arrangement until the image of the object is very sharp. To avoid parallax between the image of the distant object and that of the cross-wire, the eye-piece tube is to be drawn in or out very *slowly* until there is *no relative movement between these two images,* as the eye is moved in a line which is perpendicular to the axis of the telescope tube.

(*iii*) To focus a very near object by a microscope, the microscope is to be directed towards that object and the *microscope tube should be slowly moved as a whole,* either towards or away from the object, until the image of the object is very sharp. To avoid parallax between the image of the near object and that of the cross-wires, the microscope tube should be moved very *slowly* until there is no *relative movement between these two images,* as the eye is moved in a line which is perpendicular to the axis of the microscope tube.

(d) Index-error and how to eliminate it : To perform experiments with the help of an optical bench, an error known as the index error always arises. This error is due to the incorrect marking of the index line at the base of the vertical stands which can slide on the scale of the bench. Hence a correction for this error is necessary.

[For correction of index error, see Art. 1, p. 3]

3. Camparison of the Luminous intensities of two sources of light by Bunsen's photometer.

Apparatus : Bunsen photometer consists of an unglazed white paper fitted to a frame. At the middle region of this paper, there is a small circular grease-spot *G* which is more transparent than the rest of the paper.

This photometer can be mounted on an upright fitted to an optical bench. On the two opposite sides of this grease spot, two sources of light S_1 and S_2 (whose luminous intensities are to be compared) can also be mounted on suitable uprights fitted to the bench (Fig. 3). These three uprights, carrying the photometer and the two sources, are provided with index marks at their bases and they can be made to move by the side of the horizontal scale of the bench, as is shown in Fig. 3.

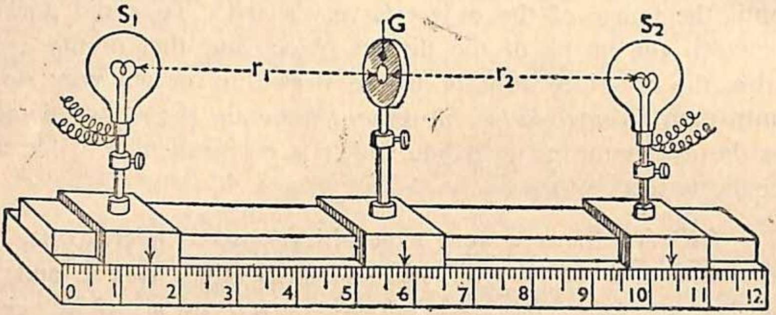

Fig. 3

Theory : When two sources S_1 and S_2 of light placed on the opposite sides of the grease-spot G [Fig. 3] are adjusted so that the grease-spot and the rest of the paper are equally bright, the normal illumination $E_1\left(=\frac{I_1}{r_1^2}\right)$ by the first source S_1 on the grease-spot G becomes equal to the normal illumination $E_2\left(=\frac{I_2}{r_2^2}\right)$ by the second source S_2 on the same grease-spot G. That is,

$$\frac{I_1}{r_1^2}=\frac{I_2}{r_2^2}\text{ ; or, }\frac{I_1}{I_2}=\frac{r_1^2}{r_2^2} \quad \cdots \quad \cdots \quad (1)$$

Here I_1 and I_2 are respectively the luminous intensities of the first source S_1 and the second source S_2, while r_1 and r_2 are their respective distances from the grease-spot G when balance on the photometer is obtained. By employing the relation (1) the luminous intensities of the two sources can be compared.

Procedure : (*i*) Three uprights are fitted to a suitable form of optical bench. The photometer is mounted on the middle upright, while the two given sources of light (S_1 & S_2) are mounted on the two extreme uprights [Fig. 3]. Adjustments are made to bring the centres of the two sources S_1 and S_2 and the centre of the grease-spot G in one horizontal straight line parallel to the axial line of the bench.

(*ii*) The index error λ_1 between the source S_1 and the grease-spot G as well as the index error λ_2 between the source S_2 and the grease-spot are separately determined in the usual way [see Art. 1].

(*iii*) The two sources S_1 and S_2 are kept at a fixed distance apart and the readings A and B respectively of the bench scale corresponding to the index marks at the base of their uprights are noted.

(*iv*) The position of the upright carrying the photometer is now adjusted until the grease-spot and the rest of the paper are equally bright. The reading C of the bench scale corresponding to the index mark at the base of this upright carrying the grease-spot is noted. This observation is repeated thrice and the mean of these three readings (*i.e.* mean C) is found out. Thus we get the distances r_1 $(=C\sim A)$ and r_2 $(=C\sim B)$ of the sources S_1 and S_2 respectively from the grease-spot G when balance is obtained.

(*v*) The operations (*iii*) and (*iv*) are repeated for two other fixed distances between the sources S_1 and S_2.

(*vi*) The positions of the sources are then interchanged and the operations (*iii*), (*iv*) and (*v*) are repeated for those three fixed distances between S_1 and S_2 as were formerly employed.

(*vii*) The ratio I_1/I_2 is found out from each of the observations and the mean of these six ratios will give the exact value of the ratio I_1/I_2.

Experimental data :

(A). *To find the index errors* λ_1 *and* λ_2 *between* S_1 *and* G*, and also between* S_2 *and* G *respectively :—*

TABLE I

Length of index rod in cm. (l)	Diff. of bench-scale readings in cm. when the two ends of index rod touch the,		Index error in cm. between,	
	Source S_1 and the screen G (d_1)	Source S_2 and the screen G (d_2)	S_1 & G is $\lambda_1 = l - d_1$	S_2 & G is $\lambda_2 = l - d_2$
$l = ...$cm.	$d_1 = (...) - (...)$ $= ....$cm.	$d_2 = (...) - (...)$ $= ....$cm.	$\lambda_1 = ...$cm.	$\lambda_2 = ...$cm.

(B). *To find the distances* r_1 *and* r_2 *of the sources* S_1 *and* S_2 *respectively from* G *:—*

TABLE II

No. of obs	Sources in the		Positions in cm. of			Mean (C) in cm.	App. distances in cm. between		Corrected distances in cm. of		Values of	Mean I_1/I_2
	Left	Right	Source S_1 (A)	Source S_2 (B)	Screen G (C)		S_1 & G = $r'_1 = (C \sim A)$	S_2 & G = $r'_2 = (C \sim B)$	$r_1 = r'_1 + \lambda_1$	$r_2 = r'_2 + \lambda_2$	$\frac{I_1}{I_2} = \frac{r_1^2}{r_2^2}$	
1	S_1	S_2	...	...	... ...	...	...	...	...	...	...	....
2	,,	,,	...	...	... ...	...	...	...	....	...	...	
3	,,	,,	...	...	... ...	...	...	...	...	...	...	
4	S_2	S_1	...	...	... ...	...	...	...	...	...	...	
5	,,	,,	...	...	... ...	...	...	...	...	...	...	
6	,,	,,	...	...	... ...	...	...	...	...	...	...	

Calculations :

$$\frac{I_1}{I_2}=\frac{r_1^2}{r_2^2}=\cdots=\cdots$$

Discussions : — (*i*) Due to absorption of light by the greased portion of the paper, the greased portion can never be made equally bright with the rest portion. But we can make the spot equally bright on either side. For this purpose two plane mirrors M_1 and M_2 are kept on the two sides of the screen G, each being inclined with the screen by an angle of 45°. By this, the two sides of the spot can be viewed simultaneously to judge the equality of brightness.

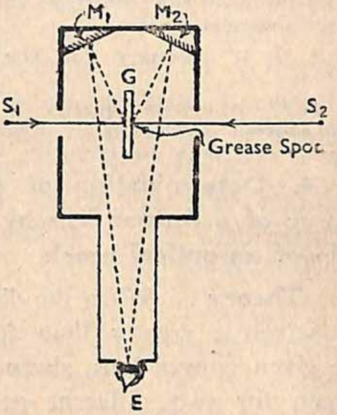

Fig. 3(*a*)

(*ii*) If the two sources are not emitting light of same colour then the equality of brightness can never be realised.

(*iii*) The sources are to be interchanged, to eliminate the effects of illumination of the screen by stray reflections from the wall or any other surface.

(*iv*) As $I_1/I_2=r_1^2/r_2^2$, the ratio I_1/I_2 should be neither too large nor too small otherwise a small error in the measurement of r_1 or r_2 will introduce a large percentage error in the value of I_1/I_2. For greater accuracy, r_1 and r_2 should be large so that a small error in their measurement will not introduce large error in the result.

Oral Questions and their Answers

1. Explain the meaning of the terms :—(*a*) Luminous flux, (*b*) illumination, (*c*) Luminous intensity, (*d*) Candela, (*e*) Lumen, (*f*) Phot and Lux.

(*a*) Luminous flux through an area is the quantity of light that flows per sec. through that area. (*b*) Illumination at a point is the amount of luminous flux through unit area surrounding the point, (*c*) Luminous intensity of a source in a given direction is the amount of luminous flux radiated per unit solid angle in that given direction. (*d*) Candela is the unit of luminous intensity which is $\frac{589}{600}$ of the old British candle power. (*e*) Lumen is the luminous flux radiated per unit solid angle by a source of luminous intensity one candela. (*f*) The illumination of a surface of 1 sq. cm. or 1 sq. metre are respectively called Phot or Lux according as 1 Lumen passes normally through that area held at a distance of 1 cm. or 1 metre respectively from a source of luminous intensity one candela.

2. How do the illumination and luminous intensity vary with distance ? Illumination at a point varies inversely as the square of the distance of the point from the source while luminous intensity of a given source is constant.

3. Is it necessary that the two sources should emit light of same colour ?

Yes ; otherwise equality of brightness cannot be judged. If the two sources emit light of different colours, then Flicker photometer (see '*Text Book on Light*' by the author) should be employed.

4. Determination of the focal length and hence the power of a convex lens by displacement method with the help of an optical bench.

Theory : When the distance (D) between the object and the screen is greater than four times the focal length (f) of the given convex lens, sharp image can be cast on the same screen for two different positions of the lens. If x be the distance between the two positions of the lens, *i.e.* the displacement of the lens, then the focal length f of the lens with its sign is given by,

$$f = -\frac{D^2 - x^2}{4D} \quad \cdots \quad \cdots \quad \cdots \quad (1)$$

This relation (1) is employed to find the focal length of a convex lens.

The power P of the lens in Dioptre is given by,

$$P = -\frac{100}{f \text{ in cm.}} \text{ dioptres} \quad \cdots \quad \cdots \quad (2)$$

Procedure : (*i*) The cross-wire of the object screen is illuminated by the light of an electric lamp and the index of this stand is kept at a fixed mark at one end of the bench scale. The reading (A) of the scale corresponding to the index is noted. This position of the object stand is kept fixed throughout the experiment.

(*ii*) A convex lens is kept on a stand between the object and the screen and the heights of the object, the lens and the screen from the bench are adjusted so that the centres of the cross-wire, the lens and the image screen are all in one horizontal straight line. Next the index error ($= \lambda$) between the object and the screen is determined in the usual way (see Art. 1).

(*iii*) At first, the position of the screen is so adjusted that a sharp image is formed on it *for two different positions of the convex lens which are small distance apart*, i.e. the displacement of the lens is small. When this care is taken, we get magnified image for one position of the lens (nearer to the object) and diminished image for the other position of the lens (nearer to the screen) and the size of the diminished image is of such a dimension, that its sharpness can be clearly distinguished from its out-focussed condition. Keeping this position of the screen fixed, the reading (B) of the bench scale corresponding to the index mark on the screen-stand is noted. Then the apparent value of D is, $D_1 = (A \sim B)$. Corrected value of D is given by $D = (D_1 + \lambda)$.

(*iv*) The first position of the lens is adjusted nearer to the object until a sharp magnified image is formed on the screen. The position of the lens is noted from the bench scale. This operation is repeated thrice, the mean of which gives the first position (R_1) of the lens.

(*v*) Next the second position of the lens is adjusted nearer to the screen until another sharp diminished image is formed on the same screen. The position of the lens is again noted from the bench scale. This operation is also repeated thrice and the mean of these three readings gives the second position (R_2) of the lens. The displacement of the lens is thus obtained as, $x = (R_1 \sim R_2)$.

(*vi*) The position of the screen is then shifted to three or four different positions by displacing it by steps of 2 or 3 cm., so that the value of D may be greater or smaller than its preceding value by about 2 or 3 cm. At each value of D, the operations (*iv*) and (*v*) are repeated. Thus for three or four different values of D, we get three or four different values of x and in each case the value of f is calculated from the relation (1). The mean of these three or four values of f is the actual focal length of the lens. When this mean value of f (with its sign) is put in the eqn. (2) we get the power P of the lens.

Experimental data :

(A). *Index error* (λ) *for D* :—

TABLE I

Length of index rod in cm. (l)	Diff. of bench-scale readings in cm. when the two ends of index rod touch the object and screen (d)	Index error for D in cm. is $\lambda = (l - d)$ cm.
$l = \ldots$cm.	$d = (\ldots) - (\ldots)$ $= \ldots$cm.	$\lambda = \ldots$cm.

(B). *Records of the data for D and x* :—

TABLE II

No. of obs.	Positions in cm. of		App. D in cm. is $D_1 = (A \sim B)$	Corrected D in cm. is, $D = (D_1 + \lambda)$	*First position* of lens in cm. (R_1)	Mean R_1 in cm.	*Second position* of lens in cm. (R_2)	Mean R_2 in cm.	$x = (R_1 \sim R_2)$ in cm.	$f = -\frac{D^2 - x^2}{4D}$ in cm.	Mean f in cm. (with sign)	$P = -\frac{100}{f}$ dioptre.
	Object (A)	Screen (B)										
1.	91	50	41	$41 + \lambda$ $= \ldots$	74 74·2 74·1	74·1	66·8 66·6 66·5	66·6	7·5	$-$ (...)	$-$ (...) cm.	+ (...) dioptre
2.	.	46·8	44·2	$44{\cdot}2 + \lambda$ $= \ldots$	76·5 76·4 76·6	76·4	62·2 62·4 62·2	62·3	14·1	$-$ (...)		
3.	,,	...	...	...	... ...	...	... ...	...	...	$-$ (...)		
4.	,,	...	...	...	... ...	...	... ...	...	...	$-$ (...)		

Calculation :

Formula employed is $f=-\frac{D^2-x^2}{4D}$

$$(i)\quad f=-\frac{(\cdots)^2-(\cdots)^2}{4\times(\cdots)}=-(\cdots)\text{cm.}$$

$$(ii)\quad f=-\quad(\cdots)\quad=-(\cdots)\text{cm.}$$

$$(iii)\quad f=-\quad(\cdots)\quad=-(\cdots)\text{cm.}$$

$$(iv)\quad P=-\frac{100}{\text{mean } f \text{ in cm.}}=+(\cdots)\text{ dioptre}$$

(*i*) To have minimum proportional error in the value of '*f*' the displacement *x* of the lens should be small* and hence *D* should be adjusted accordingly.

(*ii*) As a small change in the value of *D* causes a large change in the value of *x***, the value of *D* should be changed by 2 or 3 cm. nearly in different observations.

Oral Questions and their Answers

1. Define focal length.

By the term 'focal length of a lens' we mean its second focal length and it is the image distance when the object distance is infinity *i.e.* incident rays are parallel.

---

*The numerical value of focal length is, $f=\frac{D-x^2}{4D}$. Hence for a given value D, the proportional error in f for a small error δx in the measurement of x is given by, $\frac{\delta f}{f}=-\frac{2x\delta x}{D^2-x^2}$. Thus the proportional error in f viz. $\frac{\delta f}{f}$ would be minimum when the fraction $\frac{x}{D^2-x^2}$ is small *i.e.*, when x is small.

**When the expression $f=\frac{D^2-x^2}{4D}$ is differentiated and simplified we get a relation connecting the variation of D, viz., δD with the variation of x, viz. δx and this relation is given by,

$$\delta x=\frac{D-2f}{x}.\ \delta D.$$

For a given change δD of D, the corresponding change δx in x would be large, for δD is multiplied by factor $\frac{D-2f}{x}$ which is greater than unity (for $D>4f$ and x is also small).

2. How many focal lengths are there and which is accepted by you? What is the sign of the focal length?

There are two focal lengths, first and second. First focal length is the object distance whose image distance is infinity. We accept the second focal length whose sign is $-ve$ for convex and $+ve$ for concave lens.

3. Are the two focal lengthe equal or different?

They will be equal when the lens is surrounded by the same medium but will be different when the incident and emergent media are different.

4. Does the focal length change with colour?

Yes; for, $\frac{1}{f}=(\mu-1)\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$. Hence f depends on μ and the curvature of two surfaces. As μ is greater for violet light than for red light, f is smaller for violet than for red. Increase of curvature $\left(=\frac{1}{r}\right)$ will also shorten the focal length.

5. Why do you keep the distance between the object and the screen greater than $4f$?

Otherwise two real images cannot be obtained.

6. What is the minimum distance between the object and its real image formed by a convex lens? $4f$.

7. Is it advisable to make D large?

No; in that case diminished image will be very small and its focussed condition cannot be detected.

8. When you immerse the lens in water, will its focal length be the same as before?

No: its focal length will be 4 times greater than in air.

9. Why is the index correction for x unnecessary here?

For the displacement of the lens must be equal to the displacement of the index of the stand on which the lens is kept.

10. Why is one image magnified while another image is diminished?

Magnification of the image $=\frac{\text{Image distance}}{\text{Object distance}}$. When the lens is nearer to the object, the image distance is large and hence the image is magnified, while the reverse occurs when the lens is nearer to the screen.

11. By employing your data can you find f by graphic method?

Yes; the focal length with its sign is given by $-f=\frac{D^2-x^2}{4D}$ or, $\frac{x^2}{D}=D+4f$. If $\frac{x^2}{D}$ is plotted along y-axis while D is plotted along x-axis, we get a straight line cutting both y and x-axes. The intercept made by this straight line on the x-axis is $-4f$. Since when y is zero, i.e. x^2/D is zero we get D (the intercept on x-axis) equal to $-4f$.

12. Can you measure the size of the object by measuring the sizes of the images?

Yes : if I_1 and I_2 are sizes of the two images, then the size of the object is given by, $O=\sqrt{I_1 I_2}$.

5. Determination of the focal length and hence the power of a convex lens by drawing a graph between the distances of its conjugate foci.

(a) By using optical bench.

Theory : After proper consideration of the signs of the object distance (u), and the image distance (v) of convex lens forming a real image, the focal length (f) of the lens is given by,

$$\frac{1}{f}=-\left(\frac{1}{u}+\frac{1}{v}\right) \qquad \ldots \qquad \ldots \qquad (1)$$

By obtaining the various values of v corresponding to different values of u, if we draw a graph plotting u along the x-axis while v along the y-axis, so that the origins of both u and v are the same and the scales of their representations along the two axes are also equal, then we shall get a rectangular hyperbola [Fig. 4]. If a straight line be drawn from the origin by making an angle of 45° with the axes, then it will cut the curve at P whose co-ordinates will be equal, *i.e.* u and v will be equal. Putting this condition in equation (1), we get $-\frac{2}{u}=\frac{1}{f}$, or, $u=-2f$ and $v=-2f$. Thus

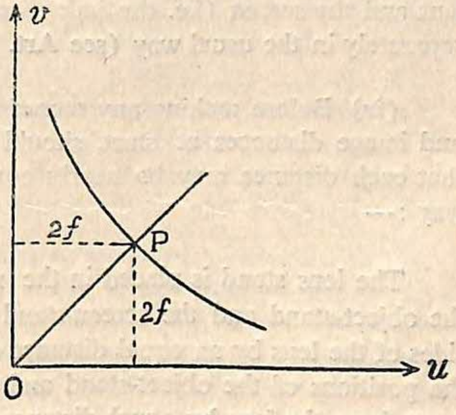

Fig. 4

half of the values of the co-ordinates of P with negative sign will give focal length of the convex lens with its sign.

The power (P) of the lens is then given by,

$$P = -\frac{100}{f \text{ in cm.}} \text{ dioptres} \quad \ldots \quad \ldots \quad (3)$$

Procedure : (*i*) The maximum thickness (t) at the centre of the lens (equi-convex) is measured several times by a slide callipers and the mean thickness (t) is found out.

(*ii*) The cross-wire of the object-stand is kept at a certain height from the bench and it is strongly illuminated by an electric lamp from behind. In front of this object-stand there are two other stands for mounting convex lens and the screen respectively.

The given convex lens is mounted on the second stand while the screen is placed on the third stand. The heights of the lens and the screen are adjusted until the centres of the cross-wire (object), the convex lens and the screen are all in one straight line parallel to the bench.

(*iii*) The index error λ_1 between the lens and the object (*i.e.* index error for u) as also the index error λ_2, between the lens and the screen (*i.e.* the index error for v) are determined separately in the usual way (see Art. 1).

(*iv*) Before making any record of $(u-v)$ data, the object and image distances at start, should be made nearly equal (so that each distance may be nearly equal to $2f$) in the following way :—

The lens stand is placed in the middle of the bench while the object-stand and the screen-stand are placed on the opposite sides of the lens by an equal distance of about 5 cm. (say). Then the positions of the object-stand and the screen-stand are shifted away from the lens by equal distances (say by 1 or 2 cm.) until we get a sharp image on the screen. Let d be now the distance between the lens and the cross-wire or between the lens and screen. The distance *d* would be nearly equal to $2f$ and the object distance at start should be made equal to *d*.*

(*v*) The object-stand is now shifted to one extremity of the bench and the index of this stand is made to coincide with a definite mark (say integral number) of the bench scale. The reading (A) corresponding to the index of the object-stand is noted and this reading is kept fixed throughout the experiment.

(*vi*) The convex lens stand is now kept at a distance *d* or $2x$ (nearly equal to $2f$) in front of the object-stand and the reading (B) corresponding to the index of this stand is noted.

(*vii*) The position of the screen is now adjusted *independently for three times* to form a very sharp image on the screen and in each case the reading (C) of the index of the screen-stand is noted. The mean of these three readings, *i.e.* mean (C) gives the position of the image.

The apparent object distance is, $u_1 = (B \sim A)$ while the apparent image distance is given by, $v_1 = (C \sim B)$. The corrected values of the object and image distances are obtained by adding algebraically the values of λ_1 (the index error for object distance) and λ_2 (the index error for image distance) to u_1 and v_1 respectively. Thus we get, corrected $u = (u_1 + \lambda_1)$, while corrected $v = (v_1 + \lambda_2)$.

(*viii*) The lens-stand is then shifted and kept fixed at 6 more independent positions, three towards the object side (in which *u* will be less than $2f$) while three towards the screen side (in which *u* will be greater than $2f$).† At each fixed position of the lens the screen position is adjusted independently for three times to cast a sharp image on the screen. The positions of the screen are noted from the bench scale and the mean of these three different positions of the screen (C) is found out for each positions of the lens. In each of the six positions of the lens, the apparent object distance is $u_1 = (B \sim A)$ while the apparent image distance is $v_1 = (C \sim B)$ are determined from which the corrected values of u and v are found out as is indicated in (*vii*).

---

*Another method of finding approximately the focal length of the lens is to put the illuminated cross-wire (object) and the screen at the two extreme ends of the bench and then to bring the lens close to the screen until a sharp image is formed on the screen. The distance x of the screen from the lens is approximately the focal length of the lens and hence the starting object distance should be $2x$.

† If the values of the nearly equal object and image distances are each 20 cm. then shift the lens by 2 cm. If those equal distances are each equal 30 cm. nearly, then shift the lens by 3 cm.

(ix) These corrected values of u and v are plotted on a graph paper with u along the x-axis, while v along the y-axis, the representations along both the axes are equal. Now a straight line is drawn from the origin by making an angle of 45° with the co-ordinate axes. The ordinate or the abscissa of the cutting point of this straight line with the $(u-v)$ curve is found out and half of this ordinate or abscissa with negative sign is the focal length of the lens with its sign.

When this focal length (in cm.) with its sign is put in the relation (2) we get the power of the lens in dioptre.

Experimental data :

(A). *Thickness (t) of lens (equi-convex) by slide callipers :—*

TABLE I

[Make a table for slide callipers as given in Expt. 10, Part I and take *at least* 4 observations.]

(B). *Index errors* λ_1 and λ_2 *for* u *and* v *respectively :—*

TABLE II

Length of index rod in cm. (l)	Diff. of bench-scale reading in cm. when the two ends of index rod touch the,		Index error in cm. for	
	lens and centre of cross-wire (d_1)	lens and the screen (d_2)	u is, λ_1* $=(l+t/2)-d_1$	v is, λ_2* $=(l+t/2)-d_2$
$l = \cdots$ cm.	$=(\ldots)=(\ldots)$ $=\ldots$cm.	$d_2=(\ldots)-(\ldots)$ $=\ldots$ cm.	$\lambda_1=(\ldots)$ $-(\ldots)=$ $\pm\ldots$cm.	$\lambda_2=(\ldots)$ $-(\ldots)=$ $\pm\ldots$cm.

* In the case of a *thin equi-convex lens*, the distances are measured from optical centre which is situated at a distance of $t/2$ from the surface. Hence $t/2$ should be added. For *thick lens*, the distances are measured from principal points which are situated at distances $t/3$ from surfaces. Hence in that case $t/3$ should be added.

(C). *($u-v$) records* :—

TABLE III

No. of Obs.	Positions in cm. of			Mean (C) in cm.	Apparent distances in cm. of,		Corrected distances in cm. of,		f in cm. from graph	$P=-\frac{100}{f \text{ in cm.}}$ dioptre
	object (A)	lens (B)	screen (C)		object $=u_1=(B\sim A)$	image $=v_1=(C\sim B)$	object $=u=u_1+\lambda_1$	image $=v=v_1+\lambda_2$		
1.	91·1	72	51·8 51·9 52	51·9	19·1	20·1	19·1+ (λ_1) = ...	20·1+ (λ_2) = ...	$-$ (... cm	+ (...) dioptre
2.	,,	70	51 51·4 50·8	51·1	21·1	18·9	21·1+ (λ_1) = ...	18·9+ (λ_2) = ...		
3.	,,	68	... ...	...	...	...	...	...		
4.	,,	66	... ...	...	...	...	...	...		
5.	,,	74	... ...	...	...	...	...	...		
6.	,,	76	... ...	...	...	...	...	...		
7.	,,	78	... ...	...	...	...	...	...		

(D). *Drawing of $(u-v)$ graph* :—

A graph, connecting u and v is drawn with the following sample data as is shown in Fig. 5.

Corrected $u \rightarrow$	22·7	25·4	28·7	31·4	34·7	37·4	41·3
,, $v \rightarrow$	53·9	43·1	38	32	29·9	28·1	26

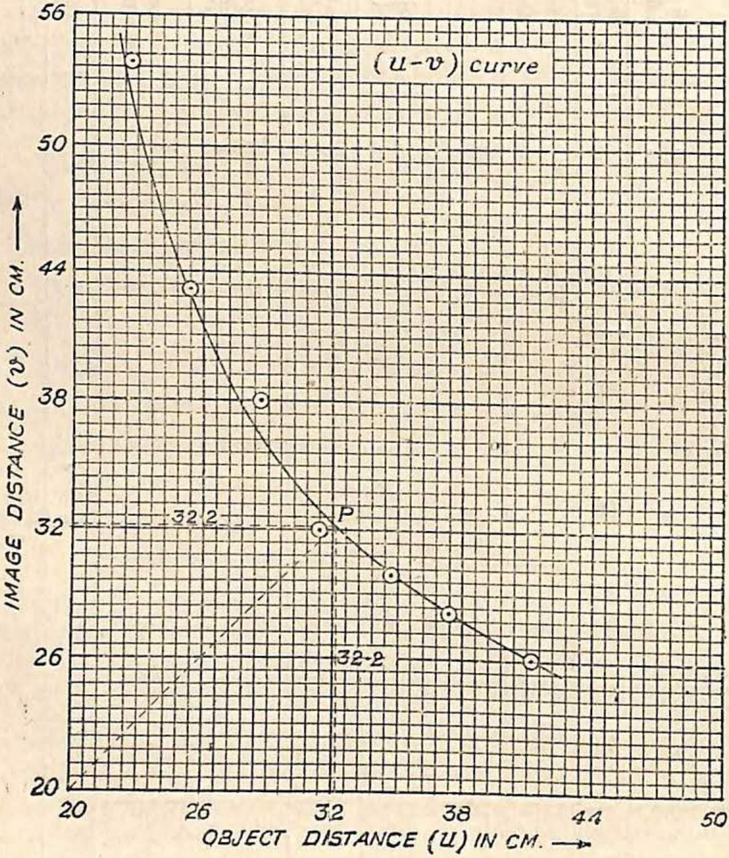

Fig. 5

From the above data, lowest values of u and v are taken and then a round number, even lower than the lowest of the values of u and v (here, 20) is selected as the origins for both

u and v. Here u and v should respectively be plotted along x-and y-axes. Next the highest values of both u and v are taken from the given data and a round number even greater than the highest of the values of u and v (here, 56) is found out. The difference between this highest round number (*viz.* 56) and the value at the origin (*viz,* 20) should be divided amongst the number of divisions of graph paper (which must be taken equal along both axes) available along an axis. After plotting various points, a smooth curve is drawn, which is the required $(u-v)$ curve. Now a straight line is drawn from the origin at an angle of 45° with the axes cutting the curve at a point P, the co-ordinates of which (here, 32·2, 32·2) will be $2f$ and half of this value (here, 16·1) will be the numerical value of the focal length.

N. B. [There are two other graphical methods of finding f :—

1. Taking the same value, as the origins for u and v and the same scale of representations along the two axes the lengths of x-axis and y-axis are measured off equal to the values of u and v respectively which are obtained in the first pair of data. These two points on the two axes, when joined, we get a straight line. In this way we get several straight lines for several pairs of u and v [Fig. 6]. These straight lines intersect at a point (P) the co-ordinates of which will be equal and each will be numerically equal to f [Fig. 6].

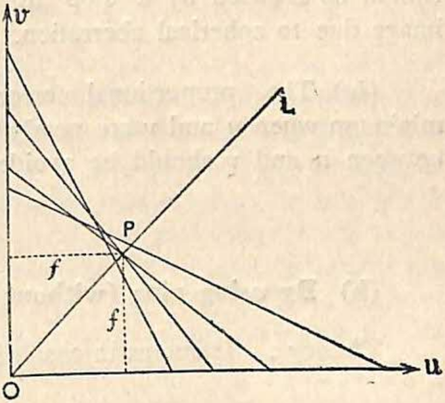

Fig. 6

This common point (P) of intersection of $(u-v)$ lines should lie on the straight line (OPL) drawn from the origin making an angle of 45° with the axes But due to experimental error, these $(u-v)$ lines never cut at a point. Here the mean value of the ordinates (or abscissa) of the points of intersection of 45°—line with the various $(u-v)$ lines will give the mean focal length.

2. Choosing $(0-0)$ as the origin and same scale of representations along the two axes, $1/u$ is plotted along x-axis while $1/v$ is plotted along

y-axis. The graph would be a straight line making equal intercepts on the two axes. The reciprocal of the value of any one of two equal intercepts will give the focal length. For in the relation $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$, we see that when $\frac{1}{v}=0$; $\frac{1}{u}=\frac{1}{f}$. The intercept on the x-axis is $1/u$. the reciprocal of which is f.]

Precautions : (*i*) To get equal distribution of points on both sides of 45° straight line, the starting object distance should be made nearly equal to $2f$. Then image distances are to be noted for six more different object distances; three should be made greater than $2f$ by steps of about 2 or 3 cm. while the other three should be made less than $2f$ by the same steps.

(*ii*) The object distances should be made greater than the focal length of the lens otherwise real image cannot be obtained.

(*iii*) When the size of the lens is very large its aperture should be reduced by a stop to avoid the distortion in the image due to spherical aberration.

(*iv*) The proportional error in measuring f would be minimum when u and v are nearly equal. Hence large difference between u and v should be avoided.

(b) By using pins (without optical bench).

Theory : [same as in case of Expt. 5 (*a*)].

Procedure : (*i*) The maximum thickness t at the centre of the given convex lens (equi-convex) is first measured by a slide callipers and the value of $t/2$ in cm. is found out.

(*ii*) The convex lens L is then placed at a suitable height on a lens-holder fitted to a stand kept on the table (Fig. 7). Two pins P (object pin) and I (image pin) of adjustable heights are mounted on suitable stands and kept on the two sides of the lens. The heights of the tips of these pins are adjusted so that the line joining *P*, *O* (centre of the lens) and *I* is a straight line parallel to the table.

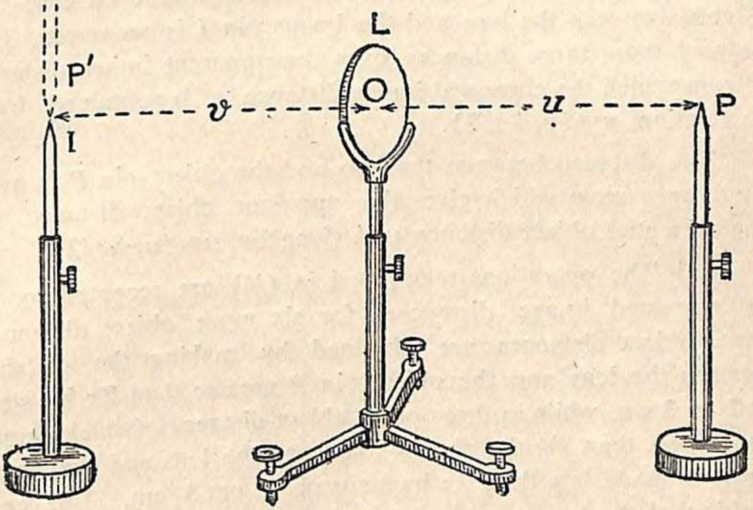

Fig. 7

(*iii*) At first a preliminarly observation is to be made to have the starting value of u (object distance) nearly equal to $2f$.

The object pin *P* is kept at one end of the long working table while the image pin *I* is kept at the opposite end of the table. The stand containing the convex lens is brought close to the image pin *I* until the inverted real image *P′* of the object pin *P*, coincides with the pin *I* and there is no parallax between *I* and *P′*. The distance x of the image pin *I* from the convex lens is approximately the focal length of the lens and the starting value of the object distance should be made equal to $2x$*.

(*iv*) The object pin *P* is now placed at a distance $2x$ from the lens and the image pin *I* is adjusted on the other side of the lens until the tip of the real inverted image P' of the object P, coincides with the tip of the pin I and there is no parallax between I and P'. This coincidence of the pin I with the inverted image P', is repeated three times and in each case the distance between the lens and the image pin I is measured. The mean of these three distances gives the apparent image distance v_1 from which the corrected image distance v is obtained from the relation, $v=(v_1+t/2)$.

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* Another method of finding approximately the focal length of the lens is to focus sharply the image of a distant object, such as a distant electric lamp or a window bar, on a piece of white paper by moving the convex lens towards the paper. The distance x between the lens and the paper is approximately the focal length of the lens. Thus the object distance at start should be made euqal to $2x$.

The distance between the lens and the object pin P is measured by a scale which gives the apparent object distance u_1. The corrected object distance u is given by, $u=(u_1+t/2)$.

(*v*) The operations mentioned in (*iv*) are repeated to get six corrected image distances, for six more object distances. Three object distances are obtained by making the distance between the lens and the object pin P greater than $2x$ by steps of 2 or 3 cm. while in three other object distances (which should not be less than f), the distance between the lens and the object pin P is made less than $2x$ by steps of 2 or 3 cm. For each position of the lens, corrected u and corrected v are determined.

(*vi*) Then a graph is drawn with u along the x-axis while v along the y-axis so that the origins of both u and v are the same and their representations along the axes are also equal.

A straight line is drawn from the origin making an angle of 45° with the axes and half of the co-ordinates of the point of intersection of this straight line with the $(u-v)$ curve, when taken with negative sign we get the focal length of the given convex lens [Fig. 5]. When this focal length (in cm.) with its sign is put in the relation (2) we get the power of the lens in dioptre.

Experimental data :

(A). *Thickness (t) of the lens (thin equi-convex) by slide callipers :—*

TABLE I

[Make a table for slide callipers as given in Expt. 10, Part I and take *at least* 4 observations.]

(B). *$(u-v)$ records* :—

TABLE II

Half the thickness of lens $=t/2=$ . . . . . .cms.

No. of obs.	Apparent distances in cm. of,		Mean v_1 in cm.	Corrected distances in cm. of,		f in cm. from graph.	$P=-\frac{100}{f \text{ in cm.}}$ dioptre
	object (u_1)	image (v_1)		object, $=$ $u=u_1+t/2$	image, $=$ $v=v_1+t/2$		
1.	...	... ...	...	...	...		
2.	...	....	...	...	...	− (...) cm.	+ (...) dioptre.
etc.	etc.	etc.	etc.	etc.	etc.		
6.	...	....	...	...	...		
7.	...	... .	...	...	...		

(C). *Drawing of $(u-v)$ graph* :—

[Same as in item **(D)** of Expt. 5 (a)].

Precautions :—(i) to (iv)—[Same as those in Expt. 5(*a*).]

(v) When measuring u and v, the scale should be placed horizontally.

Oral Questions and their Answers

1–4. [Same as in Expt. 4.]

5. When will you get a real image on the screen ?

When the object distance is greater than the focal length of the lens. Magnified real image will be obtained when the object is between focus and twice the focal length, while diminished real image will be obtained when the object is between infinity and twice the focal length.

6 What is the power of a lens and what is its unit ?

The reciprocal of the focal length of a lens expressed in metre and taken with opposite sign is the power of the lens and the unit of power is Dioptre.

7. Why do you measure the thickness of the lens ?

In the case of thin lens, distances of the object and image are measured from the optical centre of the lens and in the case of an equi-convex lens this optical centre is at the middle point of the thickness of the lens. If half of the thickness of the lens is added to apparent object and image distances u_1 and v_1 respectively, we get the correct values of u and v, the object and image distances respectively as measured from optical centre.

8. Is it necessary that one pair of conjugate distances should be nearly equal ?

Yes ; for in that case the proportional error in f would be minimum.

6. Determination of the focal length and hence the power of a convex lens by conjugate foci relation method.

(a) By using optical bench.

Theory : After proper consideration of the signs of the object distance (u) and the image distance (v) of a convex lens producing real image, the focal length f of the lens is given by,

$$\frac{1}{f} = -\left(\frac{1}{u} + \frac{1}{v}\right) \; ; \text{ or, } f = -\frac{uv}{u+v}. \qquad \ldots \quad (1)$$

When the numerical values of u and v (obtained by expt.) are put in the relation (1) we get the value of the focal length of convex lens with its sign.

The power (P) of the lens can be obtained by putting the value of f with its sign in the relation,

$$P = -\frac{100}{f \text{ in cm.}} \text{ dioptre} \qquad \ldots \qquad \ldots \quad (2)$$

Procedure : (*i*) to (*viii*)—[Same as in the 'Procedure' of Expt. 5(*a*).]

(*ix*) The corrected numerical values of u and v, obtained from each set of observation, when put in the relation (1) we get the focal length f of the given convex lens with its sign. When the mean value of focal lengths obtained from different observations is put (with the sign of f) in the eqn. (2) we get the power (P) of the lens in dioptre.

Experimental data :

(A) & (B).—[Same as those in Expt. 5(*a*).].

(C). *$(u-v)$ records* :—

TABLE III

No. of Obs.	Positions in cm. of, object (A)	Positions in cm. of, lens (B)	Positions in cm. of, screen (C)	Mean (C) in cm.	Apparent distances in cm. of, Object $= u_1 = (B \sim A)$	Apparent distances in cm. of, image $= v_1 = (C \sim B)$	Corrected distances in cm. of, object $= u = u_1 + \lambda_1$	Corrected distances in cm. of, image $= v = v_1 + \lambda_2$	f in cm. $= -\frac{uv}{u+v}$	Mean f in cm.	Power $= P$ $= -\frac{100}{f}$ dioptre.
1	...	...	... ...	...	...	...	...	...	$-(\ldots)$	$-(\ldots)$	$+(\ldots)$ dioptre
2	...	..	... ...	...	...	...	....	...	$-(\ldots)$		
etc.	etc.	etc.	etc	etc.	etc.	etc.	etc.	etc.	etc.		
6	...	...	... ...	...	...	...	...	...	$-(\ldots)$		
7	...	...	... ...	...	...	...	...	...	$-(\ldots)$		

Calculations :

$$f = -\frac{uv}{u+v} = -(\ldots) = -(\ldots) \text{ cm.}$$

Precautions : (*i*), (*ii*) and (*iii*)—[Same as (*ii*), (*iii*), and (*iv*) of 'Precautions' in Expt. 5(*a*).]

(b) By using pins (without optical bench).

Theory : [Same as in the case of experiment No. 6(*a*).]

Procedure : (*i*) to (*v*)—[Same as in the 'Procedure' of Expt. 5 (*b*).].

(*vi*) The corrected numerical values of *u* and *v*, obtained from each set of observation, when put in the relation (1) we get the focal length *f* of the lens with its sign. When the mean value of the focal lengths obtained from different observations is put (with the sign of f) in the equation (2) we get the power (P) of the lens in dioptre.

Experimental data :

(A). *Thickness (t) of lens (thin equi-convex) by slide callipers :—*

TABLE I

[Make a table for slide callipers as given in Expt. 10, Part I and take at least 4 observations.]

(B). *($u-v$) records :—*

TABLE II

Half the thickness of the lens $= t/2 = \ldots\ldots$ *cms.*

No. of obs.	Apparent distances in cm. of,		Mean v_1 in cm.	Corrected distances in cm. of,		$f=-\frac{uv}{u+v}$ in cm.	Mean f in cm	Power $=P$ $=-\frac{100}{f}$ dioptre
	object (u_1)	image (v_1)		object $=$ $u=u_1+t/2$	image $=$ $v=v_1+t/2$			
1	...	... ...	...	....	...	−(..)	−(...)	+(...) dioptre
2	...	... ...	...	...	...	−(...)		
etc.	etc.	etc.	etc.	etc.	etc.	etc.		
6	...	... .	...	...	...	−(...)		
7	...	... ...	...	...	...	−(...)		

Calculations : $f=-\frac{uv}{u+v}=-(\ldots\ldots)=-(\ldots\ldots)$ cm.

Precautions : (i) to (iv)—[Same as the items (ii) to (iv) of 'Precautions' of Expt. 5(a) and the item (v) of Expt. 5(b).]

Oral Questions and their Answers

[Same as in Expt. 5]

7. Determination of the focal length and hence the power of a concave lens with help of an optical bench.

(a) By combination method :

Theory : If two lenses of focal lengths f_1 and f_2 are put in contact with each other, their equivalent focal length F is given by,

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2} \quad \dots \quad \dots \quad (1)$$

If a convex lens of shorter focal length f_1 (higher converging power) be combined with a concave lens of longer focal length f_2 (smaller diverging power)· then the combination will behave as a convex or converging lens of focal length F. The combination will then form real image of a real object. Correcting for the signs of the focal lengths, the equation (1) may be written as,

$$-\frac{1}{F}=-\frac{1}{f_1}+\frac{1}{f_2}.$$

or,
$$f_2=\frac{Ff_1}{F-f_1} \quad \dots \quad \dots \quad \dots \quad (2)$$

Finding f_1 and F experimentally and putting their *numerical* values in equation (2), we can find f_2.

Using this value of f_2 (with sign) we can find the power of the lens from the relation, $P=-\frac{100}{f \text{ in cm.}}$ dioptre .. (3

Procedure : (*i*) The focal lengths of the convex lens (f_1)) as well as that of the combination (F) are separately determined by using displacement method [Expt. 4]. By putting the *numerical values* of f_1 and F in (2), f_2 is calculated.

(*ii*) When the value of f_2 (with sign) is put in (3) we get the power (P) of the given concave lens.

Experimental data :

(A). *Index error* (λ) for D :—[Make a table as indicated in (A) of Expt. 4].

(B). *Determination of f_1 of the convex lens* :—

TABLE II

[Make a chart as in (B), in displacement method, Expt. 4, omitting the last column.]

(C). *Determination of F of the combination* :—

TABLE III

[Make a chart as in (*B*) displacement method, Expt. 4, omitting the last column.]

Calculations :

Formula employed is, $f = -\dfrac{D^2 - x^2}{4D}$ cm.

From Table II—

(*i*) f_1 = ... = $-(...)$ *cm.*

(*ii*) f_1 = ... = $-(...)$ *cm.*

(*iii*) f_1 = ... = $-(...)$ *cm.*

From Table III—

(*i*) F = ... = $-(...)$ *cm.*

(*ii*) F = ... = $-(...)$ *cm.*

(*iii*) F = ... = $-(...)$ *cm.*

$$f_2 = \frac{Ff_1}{F - f_1} = \quad \cdots \quad = \quad +(\cdots) \quad cm.$$

[By putting the *numerical values* of f_1 and F only.]

$$P = -\frac{100}{f \text{ in cm.}} = \quad \cdots \quad = \quad -(\cdots) \quad \text{dioptre.}$$

Precautions : (*i*) & (*ii*)—[Same as the precautions (*i*) and (*ii*) in Expt. 4.]

(*iii*) The focal length f_1 of the convex lens *must be shorter, i.e. its power must be greater* than that of the given concave lens otherwise the combination cannot behave as a convex lens and hence the formation of real image is impossible.

(*iv*) The error in the measurement of the focal length f_2 of the concave lens will be less if it is combined with a convex lens of focal length f_1, *slightly smaller than* f_2 so that the focal length F of the combination may be appreciably longer than f_1.

Oral Questions and their Answers

1—10. (Same as in experiment 4.)

11. Why do you require an auxiliary convex lens ?

Because, the concave lens cannot produce real image and hence it should be combined with a high power convex lens (low focal length) so that the combination is a converging one.

12. Can you do with a convex lens of any focal length ?—No [for reasons see item 11.]

13. Why do you not employ $(u-v)$ method for finding f?

For in that case, we require the thickness of the combination of lenses as well as the index corrections both for u and v. Here we require only one index correction for D and the thickness of the lens is not required.

(b) By using an auxiliary convex lens of any focal length :

Theory : When a virtual object is put inside the focal length of a concave lens, we get a real image of that virtual object. This principle is employed to find the focal length of a concave lens by using an auxiliary convex lens of any focal length.

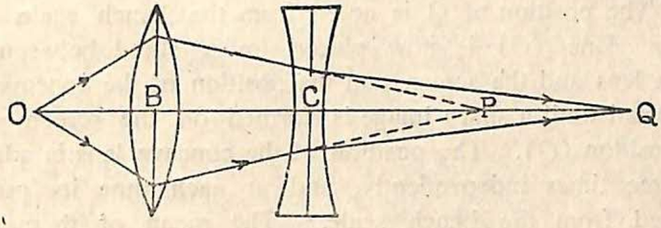

Fig. 8

In Fig. 8, the convex lens B forms a real image at P of a real object at O, when the concave lens C is absent. Now the concave lens C is so placed that the distance CP is less than its focal length and hence the real image will be formed at Q for the virtual object at P. Here object distance $=CP=-u$; image distance $=CQ=-v$.

Hence we have, $\frac{1}{-v}-\frac{1}{-u}=\frac{1}{f}$ or, $f=\frac{vu}{v-u}$ ... (1)

By using the relation (1), the focal length f of the concave lens can be found out.

By using this value of f (with its sign) we can calculate the power of the lens by using the relation,

$$P=-\frac{100}{f \text{ in cm.}} \text{ dioptres} \quad \cdots \quad \cdots \quad (2)$$

Procedure : (*i*) The object screen (O) containing a cross-wire is placed on a definite mark at one end of an optical bench [Fig. 8]. The cross-wire is illuminated by an electric lamp placed behind the screen.

(*ii*) A convex lens (*B*) is now placed on a stand between the object and the image screen, at a distance from the object screen (*O*) more than the focal length of the lens (*B*), so that a real image is formed on the screen. The position (*P*) of the image screen is adjusted until a sharp image is formed on the screen. This position of the image screen at which the sharp image is formed, is noted independently for three times. The mean of the three readings corresponding to these three positions of the screen gives the mean value of (*P*).

(*iii*) The screen is then shifted by about 5 cm. from this position (*P*) to a new position (*Q*) which is away from the convex lens. The position of *Q* is noted from the bench scale. The convace lens (*C*) is now placed on a stand between the convex lens and the screen and the position of the concave lens is adjusted until a sharp image is formed on the screen at its new position (*Q*). The position of the concave lens is adjusted for three times independently, and at each time its position is noted from the bench scale. The mean of these three readings gives (*C*). Thus we get apparent object distance $u_1=(C\sim P)$ and apparent image distance, $v_1=(C\sim Q)$.

(*iv*) The position of the screen is then shifted away from the concave lens for two or three more times by steps of 5 cm. and at each time the position (*Q*) of the screen is noted and the mean of the three independent positions (*C*) of the concave lens is found out at which a sharp image is formed on the screen. Apparent object and image distances u_1 and v_1 respectively are also found out in each case.

(*v*) The index error λ, between the concave lens and the screen, is determined in the usual way and then the corrected values of the object and image distances are respectively given by $u=(u_1+\lambda)$; and $v=(v_1+\lambda)$. When the *numerical values* of u and v are put in the formula (1), we get f from each set of observations of u and v. The mean f is then found out.

When this mean value of f (with its sign) is put in eqn. (2) we get the power of the lens in dioptre.

Experimental data :

(A). *Index error* (λ), *between the concave lens and the screen :—*

TABLE I

Length of index rod in cm. (l)	Diff. of bench-scale readings in cm. when the two ends of index rod touch the concave lens and screen (d).	Index error $=\lambda=(l-d)$ in cm.
$l=$...cm.	$d=(...)-(...)=$...cm.	$\lambda=(...)-(...)$ $=$....cm.

(B). *$(u-v)$ records :—*

TABLE II

No. of Obs.	Image position by convex lens in cm. (P)	Mean (P) in cm.	Positions in cm. of,		Mean (C) in cm.	Apparent distances in cm. of,		Corrected distances in cm. of,		$f=\frac{vu}{v-u}$ cm.	Mean f in cm.	$P=-\frac{100}{f \text{ in cm.}}$ dioptre
			image by concave lens (Q)	concave lens (C)		object $u_1=(C\sim P)$	image $v_1=(C\sim Q)$	object $u=(u_1+\lambda)$	image $v=(v_1+\lambda)$			
1.	41 41·2 41·1	41·1	36	49·1 49 49·2	49·1	8	13·1	8+(...) =...	(13·1)+ (...)=...	...	+ (...) cm.	− (...) dioptre
2.	,,	,,	31	... ...	...	...	...	...	...	...		
3.	,,	,,	26	... ...	...	...	...	...	...	...		
4.	,,	,,	21	... ...	....	...	...	...	...	...		

Calculation :

Formula employed is, $f=\frac{uv}{v-u}$. [Put *numerical* values of u and v]

(*i*) $f=$ ... $=$ ... cm.

(*ii*) $f=$ ... $=$ ... cm.

(*iii*) $f=$ ... $=$ ... cm.

(*iv*) $P=-\frac{100}{\text{mean } f \text{ in cm.}}=-(\cdots)=-(\cdots)$ dioptres.

Procedure : (i) The image due to the concave lens should be focussed on the screen *by shifting the position of the concave lens* and not by moving the screen, otherwise the focussed condition of the image will not change within an appreciable range of the movement of the screen.

(*ii*) For greater accuracy in measurement, the focal length of the convex lens employed *should not differ* from that of the concave lens *by a very large* extent.

Oral Questions and their Answers

1—4. [Same as in Expt. 4]

5. What is the purpose of taking an auxiliary convex lens ?

A concave lens cannot produce a real image of a real object but the real image produced by the convex lens, here serves as the virtual object to the concave lens and because this virtual object is kept within the focal length of the concave lens, we get the real image of this virtual object.

6. What will happen if the convex lens forms its real image beyond the focal length of the concave lens ?

In that case the image due to the concave lens will be virtual and cannot be hold on the screen.

7. Can you do with a convex lens of any focal length ?—Yes.

8. Where would you place the object of the convex lens ?

Outside the focal length of the convex lens so that the convex lens may form a real image.

8. Determination of the focal length of a concave mirror by coincidence method.

(a) By using optical bench.

Apparatus : (1) A concave mirror *M*, fitted to an adjustable stand *S*, (2) an optical bench and (3) a pin *O* of adjustable height.

Theory : The relation between the object distance (u), the real image distance (v), radius of curvature (r) and the focal length (f) of a concave mirror is given by,

$$\frac{1}{v}+\frac{1}{u}=\frac{2}{r}=\frac{1}{f} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

When $u=r$, it is evident from eqn. (1) that $v=r$ and $f=r/2$. Thus, if by adjusting the position of an object, it is made to coincide with its own real inverted image (by avoiding parallax between the object and the image), then this object distance will be equal to the radius of curvature (r) of the mirror. Half of this radius of curvature, i.e. $r/2$ will be the focal length of the mirror.

Procedure : (*i*) The concave mirror (*M*) and the pin (*O*) are mounted on the two stands of an optical bench and they are brought very close to each other. The height of the pin is adjusted until its tip (*O*) and the pole (*P*) of the mirror are at the same height from the bench [Fig. 9].

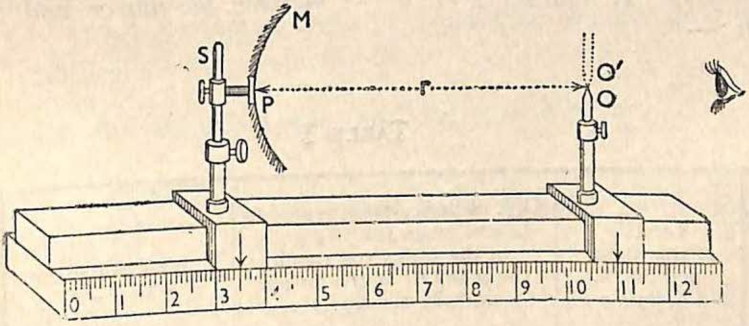

Fig. 9

(*ii*) The index error (λ) between the pin and the mirror is determined in the usual way (see Art. 1).

(*iii*) The pin (O) is then gradually moved away from the mirror until an inverted image (O') of nearly the same size as the object, is seen when looked from a distance. This time a small adjustment of the height of the pin may be necessary to make its tip just touch the tip of its inverted image. The position of the pin is now altered very slowly until there is no parallax between the tip of the pin (O) and the tip of its inverted image (O').

(*iv*) The readings R_1 and R_2 of the bench-scale corresponding to the index mark at the bases of the mirror-stand and the pin-stand respectively are noted. The apparent radius of curvature of the mirror is thus given by $r_1 = (R_1 \sim R_2)$.

(*v*) The operations (*iii*) and (*iv*) are repeated for at least five times and in each case r_1 is found out and then the mean value of r_1 is determined. The corrected radius of curvature is given by, $r = (r_1 + \lambda)$ and half of r will give the focal length of the mirror.

Experimental data :

(A) *To find index error* (λ) *between the mirror and the pin* :—

TABLE I

Length of the index rod in cm. (l)	Diff. of bench-scale readings in cm. when the two ends of the index rod touch the pole (P) of the mirror and the pin-tip (O) (d)	Index error in cm. $=\lambda=(l-d)$
$l=(\ldots)$ cm.	$d=(\ldots)-(\ldots)$ $=\ldots$cm.	$\lambda=(\ldots)-(\ldots)$ ...cm.

(B): *To find the radius of curvature r of mirror* :—

TABLE II

No. of obs.	Position in cm. of,		Apparent radius of curvature in cm. is $r_1=(R_1 \sim R_2)$	Mean r_1 in cm.	Corrected radius in cm. is, $r=r_1+\lambda$	Focal length in cm. $=f=\frac{r}{2}$
	mirror (R_1)	pin (R_2)				
1	...	...	...	...	...	...
2	...	...	...			
3	...	...	..			
4	...	...	...			
5	...	...	...			

Precautions : (*i*) An attempt to make the pin (O) coincident with its own image should be made when the image is *inverted* (real) but not when the image is erect (virtual).

(*ii*) When the aperture of the mirror is large distortion of the image will occur due to spherical aberration, curvature, etc. and for this reason parallax cannot be avoided. To remedy this defect, a stop should be employed to expose the central portion of the mirror only.

(*iii*) The image should be observed from a great distance to detect the exact coincidence.

(b) By using pins (without optical bench).

Apparatus : (1) A concave mirror M, mounted on an adjustable stand S and (2) a pin O, mounted on an adjustable stand.

Theory : [Same as in part (*a*), of this experiment No. 8].

Procedure : (*i*) The adjustable stands carrying the concave mirror (M) and the pin (O) are placed on the table and are brought very close to each other. The heights of the pole (*P*) of the mirror and the tip (*O*) of the object pin are made same from the surface of the table [Fig. 10].

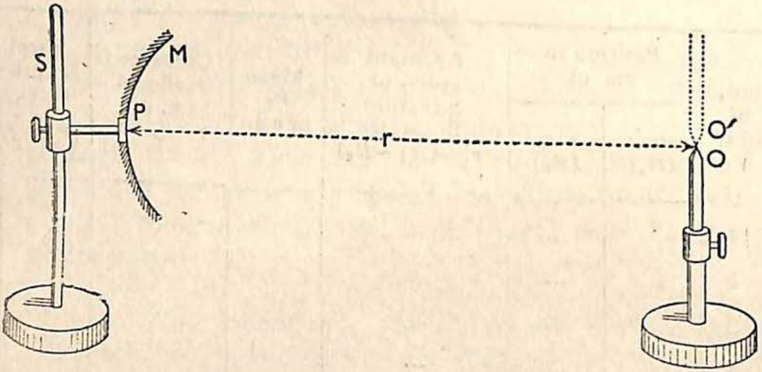

Fig. 10

(*ii*) [Same as the operation (*iii*) of part (*a*) of this expt.]

(*iii*) The distance (*r*) between the pole (*P*) of the mirror and the tip (*O*) of the pin is measured by a scale holding horizontally between them. This gives the radius of curvature (*r*) of the mirror.

(*iv*) The operations (*ii*) and (*iii*) are repeated for at least five times and the value of radius of curvature (*r*) is determined in each case. The mean of these five values of *r* when halved we get the focal length *f* of the mirror.

Experimental data :

No. of obs.	Distance between the pole (*P*) of the mirror and the pin-tip (O) in cm. (*r*)	Mean *r*. in cm.	Focal length in cm. $=f=\frac{r}{2}$
1	...	...	...
2	...		
3	...		
4	...		
5	...		

Precautions : (*i*) to (*iii*)—[Same as in the part (*a*) of this Expt. No. 8].

(*iv*) The distance between the pole (*P*) of the mirror and the pin-tip *O* should be measured by holding the scale horizontally.

9. Determination of the focal length of a concave mirror by drawing a graph between the distances of its conjugate foci.

(a) By using optical bench.

Apparatus : (1) A concave mirror *M*, fitted to an adjustable stand *S*, (2) an optical bench and (3) two pins (*O* & *I* fitted to adjustable stands.

Theory : The focal length (*f*) of a concave mirror is related to its object distance (*u*) and the corresponding real image distance (*v*) by the formula,

$$\frac{1}{f}=\frac{1}{v}+\frac{1}{u} \quad \cdots \quad \cdots \quad \cdots \quad (1)$$

By finding various values of *v* corresponding to various values of *u*, they should be plotted on a graph paper with *u* along *x*-axis and *v* along *y*-axis. The values of *u* and *v* at the origin must be the same and the scales of representation along the two axes must also be the same. The graph would be a rectangular hyperbola (Fig. 4). If a straight line be drawn from the origin by making an angle of 45° with the axes then it will cut the (*u*-*v*) curve at *P* whose co-ordinates will be equal to $(2f, 2f)$. For the point *P*, *u* and *v* are equal and hence from (1) we see that $u=v=2f$. Half of the co-ordinates of *P* will give the focal length of the mirror.

Procedure : (*i*) The concave mirror *M* is fitted to an adjustable stand *S* mounted on the optical bench [Fig. 11]. Two pins *O* and *I* are also mounted on two other stands mounted on the same bench. The heights of the pins *O* and *I* are adjusted until their tips are at the same height from the bench as that of the pole *P* of the mirror *M* [Fig. 11].

(*ii*) The index error λ_1. between the mirror M and the object-pin O and also the index error λ_2 between the mirror M and the image-pin I are separately determined in the usual way [Art. 1].

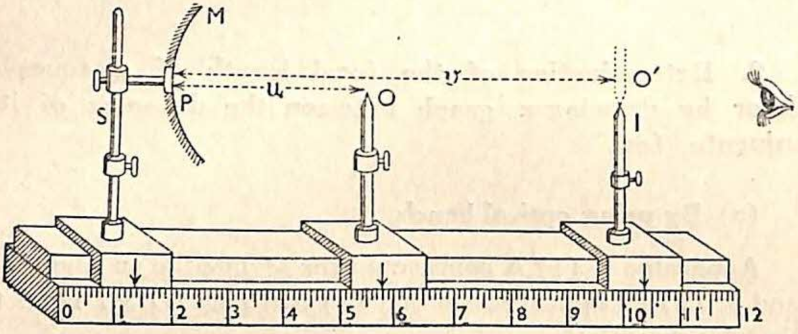

Fig. 11

(*iii*) The object-pin O is now brought close to the mirror M and then it is gradually moved away from the mirror until a real, inverted and magnified (but not too much magnified) image O' is seen when viewed from a distance. The pin I is then brought below the image O' and the position and height of the pin I are altered until its tip becomes coincident with the tip of the real image O' of the object O. This coincidence between I and O' is brought about by avoiding parallax (Art. 2).

(*iv*) The readings of the bench scale corresponding to the positions of mirror-stand (A), object-stand (B) and the image-stand (C) are noted with the help of index marks at the bases of those stands. For this particular position of the object-stand O, the position of the image-stand I is adjusted thrice to make it coincident with the image O' by avoiding parallax and in each case the reading (C) of the bench scale is noted. The mean value of (C) is then found out. The apparent object-distance is then given by $u_1=(A\sim B)$ while the apparent image distance is given by, $v_1=(A\sim C)$. The corrected object-distance will be, $u=(u_1+\lambda_1)$ while the corrected image distance will be, $v=(v_1+\lambda_2)$.

(*v*) The operation (*iii*) and (*iv*) are repeated for six different positions of the object-pin O. Three positions of O should be adjusted in such a way that it will lie between the mirror M and the image pin I (when $u<r$) to get real magnified images (but not too much magnified). The other three positions of O should be adjusted beyond the image pin I, i.e. the image-pin I should now lie between the mirror M and the object pin O (when $u>r$) so that real diminished images (but not too much diminished) may be obtained.

(*iv*) These values of u and v are now plotted on a graph paper with u along x-axis and v along y-axis. The values of u and v at the origin are made the same and the scales of representation along both the axes are also made same [Fig. 5]. The smooth curve obtained by joining the points would be a rectangular hyperbola. If a straight line is now drawn from the origin by making an angle of 45° with the axes, then this straight line will cut the curve at P [Fig. 5], the co-ordinates of which will be equal. Half of the co-ordinates of P will give the value of the focal length of the mirror.

Experimental data :

(A). *To find the index errors* λ_1 *and* λ_2 *for* u *and* v *respectively.*

TABLE I

Length of index rod in cm. (l)	Diff. of bench-scale readings in cm. when the two ends of index rod touch the,		Index error in cm. for,	
	Pole P and the object pin O (d_1)	Pole P and the image pin I (d_2)	u is, $\lambda_1 = l - d_1$	v is, $\lambda_2 = l - d_2$
$l=(\ldots)$ cm.	$d_1=(\ldots)$ $-(\ldots)$ $=(\ldots)$	$d_2=(\ldots)$ $-(\ldots)$ $=\ldots$cm.	$\lambda_1=(\ldots)$ $-(\ldots)$ $=\ldots$cm.	$\lambda_2=(\ldots)$ $-(\ldots)$ $=\ldots$cm.

TABLE II

(B). *$(u-v)$ records* :—

No. of obs.	Positions in cm. of,			Mean (C) in cm.	Apparent distances in cm. of,		Corrected distances in cm. of,		Focal length f in cm. from graph.
	mirror M (A)	object pin O (B)	image pin I (C)		object $=u_1$ $=(A \sim B)$	image $=v_1$ $=(A \sim C)$	object $=u$ $=u_1+\lambda_1$	image $=v$ $=v_1+\lambda_2$	
1	...	...	... ...	...	...	...	...	...	
2	...	...	... ...	...	...	....	...	...	
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	...
5	...	...	... .	...	...	...	...	...	
6	...	...	... ...	...	...	...	...	...	

(C). *Drawing of $(u-v)$ graph* :—

[Same as the item (D) of Expt. 5(a),]

Precaution : (i) to (iii)—[same as in the Expt. 8(a).]

(iv) The proportional error in measuring f would be minimum when $u=v$. Hence the image should not be too magnified or too diminished. That is the object distances should be slightly greater and slightly smaller than r.

(b) By using pins (without optical bench).

Apparatus : (1) A concave mirror *M*, fitted to an adjustable stand *S*. (2) two pins (*O* and *I*) fitted to adjustable stands.

Theory : [Same as in the part (*a*) of this Expt. No. 9]

Procedure : (*i*) The concave mirror *M* is fitted to a stand *S* placed on the table [Fig. 12]. Two pins *O* and *I* (which will be called as the object and image pins respectively) are also mounted on stands placed on the table and the tips of these pins are adjusted until they are at the same height from the table as the pole *P* of the mirror *M*.

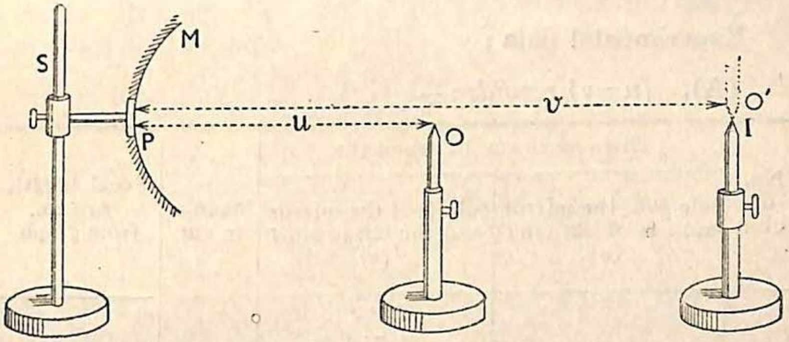

Fig. 12

(*ii*) [Same as the operation (*iii*) in the part (*a*) of this Expt. 9].

(*iii*) The distance (*u*) between the pole *P* of the mirror and the tip of the pin *O* is measured by a scale holding horizontally. This distance is the object distance *u*. The distance (*v*) between the pole *P* of the mirror and the tip of the image pin *I* is also measured by a scale holding horizontally. For this particular position of the object pin *O*, the position of the image pin is adjusted thrice to get coincidence between the image pin *I* and inverted image *O′* (the image of the object *O*, formed by reflected rays from the mirror *M*) by avoiding parallax and in each case the image distance *v* between the pole *P* and the tip of the image pin I is measured. The mean of these three image distances (v) gives the exact image distance v.

(*iv*) The operations (*ii*) and (*iii*) are repeated for six different positions of the object-pin O. Three positions of O should be such, in which it will be situated between the mirror M and the image pin I (when $u<r$) to get real magnified images (but not too much magnified) while three other positions of O should be such in which the image pin I should be situated between the mirror M and the pin O (when $u>r$), to get real diminished images (but not too much diminished).

(*v*) [Same as the operation (*vi*) in the part (*a*) of this Expt. 9].

Experimental data :

(A). *($u-v$) records* :—

No. of obs.	Distance in cm. between the		Mean v in cm.	Focal length f in cm. from graph
	pole P of the mirror and the object pin O (u)	pole P of the mirror and the image pin I (v)		
1	...	....	...	...
2	...	... ...	...	
etc.	etc.	etc.	etc.	
6	...	... .	....	

(B). *Drawing of (u−v) curve :—*

[Same as the item (D) of Expt. 5(*a*)].

Precautions : (*i*) to (*iii*)—[same as in the Expt. 8(*a*).]

(*iv*) [same as in the part (*a*) of this Expt. 9]

(*v*) The distances should be measured by holding the scale horizontally.

10. Determination of the focal length of concave mirror by (u − v) method.

(a) By using optical bench.

Apparatus : [Same as those in Expt. 9(*a*).]

Theory : The focal length f of a concave mirror is related to its object distance (u) and the corresponding real-image distance (v) by the formula :

$$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}; \qquad \text{or, } f=\frac{uv}{u+v} \qquad \ldots \quad (1)$$

The relation (1) is employed in finding the focal length f of the mirror by finding u and v for different positions of the object.

Procedure : (*i*) to (*v*)—[same as the operations (*i*) to (*v*) in the 'procedure' of Expt. 9(*a*).]

(*vi*) The values of u and v obtained from each set of observation when put in the relation (1) we get the focal length f of the mirror. The mean value of f obtained from different observations, will give the exact value of the focal length of the mirror.

Experimental data :

(A). *To find index errors* λ_1 *and* λ_2 *for* u *and* v *respectively :—*

TABLE I

[Same as in Expt. 9(*a*).]

(B). *$(u-v)$ records* :—

TABLE II

No. of obs.	Positions in cm. of			Mean (C) in cm.	Apparent distances in cm. of		Corrected distances in cm. of,		Focal length in cm. $=f=\frac{uv}{u+v}$	Mean f in cm.
	Mirror (M) (A)	object pin (O) (B)	image pin (I) (C)		object $=u_1$ $=(A\sim B)$	image $=v_1$ $=(A\sim C)$	object $=u$ $=u_1+\lambda_1$	image $=v$ $=v_1+\lambda_2$		
1	...	...	... ...	...	...	...	...	...	...	
2	...	...	... ...	...	...	...	...	...	...	...
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	
6	...	...	... ...	...	...	...	...	...	...	

Calculation :

$$f=\frac{uv}{u+v}= \quad \cdots \quad = \quad \cdots \text{ cm.}$$

etc. etc. etc.

Precautions : (*i*) to (*iv*) [Same as those of Expt. 9(*a*).]

(b) By using pins (without optical bench).

Apparatus : [Same as those in Expt. 9(*b*).]

Theory : [Same as that in the part (*a*) of this Expt. 10].

Procedure : (*i*) to (*iv*)—[same as the operations (*i*) to (*iv*) in 'procedure' of Expt. 9(*b*)].

(*v*) When the values of *u* and *v* from each set of observation are put in the eqn. (1) we get the focal length *f*. The mean of these several values of *f* will be the true focal length of the mirror.

Experimental data :

No. of obs.	Distance in cm. between the pole *P* of the mirror and the object pin (*O*), (u)	Distance in cm. between the pole *P* of the mirror and the image pin (*I*), (v)	Mean (v) in cm.	Focal length $=f=\frac{uv}{u+v}$ in cm.	Mean focal length in cm.
1	...	... ...	...	...	...
2	...	... ...	...	...	
etc.	etc.	etc.	etc.	etc.	
6	...	... ...	...	...	

Calculations :

$$f=\frac{uv}{u+v} = \dots = \dots \text{ cm.}$$

etc. etc. etc.

Precautions : (*i*) to (*v*)—[same as those in the 'precautions' of Expt. 9(*b*)].

Oral Questions and their Answers

1. Define : (*a*) pole, (*b*) radius and centre of curvature, (*c*) principal axis, (*d*) focus, (*e*) aperture of a spherical mirror.

(*a*) The middle point of the mirror surface is called pole, (*b*) The radius and centre of curvature of a spherical mirror is the radius and centre of that sphere of which the mirror is a part, (*c*) Principal axis of the mirror is the straight line joining its pole and centre of curvature, (*d*) Focus (F) of a spherical mirror is the position of the image (real or virtual) whose object is at infinity (*e*) The angle which the diameter of the outer boundary of the mirror subtends at its centre of curvature is a measure of its aperture.

2. What kind of image is produced by a concave mirror ?

Concave mirror produces virtual, magnified and erect image behind the mirror when a real object is placed within its focal length. The mirror will produce real inverted magnified image between its centre of curvature, (C) and infinity when the object is placed between F and C. The mirror will produce diminished real inverted image between F and C when the object is placed between C and ∞.

3. How would you identify a concave mirror from a plane and convex mirror without touching ?

If an object is hold very close to the mirror then we shall get a virtual erect image which will be magnified for a concave mirror, diminished for convex mirror but equal in size for a plane mirror

4. What do you mean by the term *conjugate foci* ?

Two points are said to be conjugate foci, when an object is placed at any one of these two points, an image would be formed at the other point either by reflection or by refraction.

5. Why do you reduce the aperture of the mirror when adjusting for coincidence ?

To avoid distortion in the image due to spherical aberration.

6. What is the practical application of concave mirror ?

To concentrate light in a limited area.

7. Can you employ a spherometer to find the focal length of a spherical mirror ?

Yes ; by measuring the radius of curvature of the mirror by spherometer and taking its half, we get the focal length of the mirror.

8. Can you find the focal length of a concave lens when that of a concave mirror is known ?

Yes ; By placing a pin in front of the concave lens, behind which the concave mirror is kept, the real image of the pin is made to coincide with it. The u of the lens is the distance of the pin from the lens while the v of the lens is $[r-d]$; where r is the radius of the mirror and d is the distance between the mirror and lens. Knowing u and v of the lens its f can be calculated from the formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$. Here u and v are both +ve.

11. Determination of the focal length of a convex mirror with the help of a convex lens, by using optical bench*.

Theory : Let C be the position of the real image of an object point O, formed by a convex lens L. If now a convex mirror P be placed between L and C and its position is adjusted by trial so that C is at the centre of curvature of the mirror, then the convergent rays from the lens L will be incident on the mirror P normally [Fig. 13]. These normal rays on the mirror will be reflected back along the same path and will form an image I coincident with the object O. At this condition, $(LC-LP)$ will be the radius of curvature of the mirror and half of it will give its focal length f.

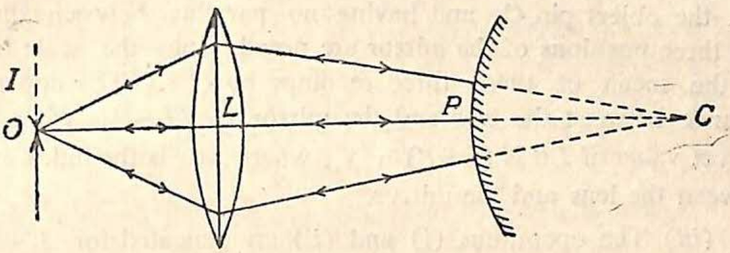

Fig. 13

Procedure : (i) The object point O (which is the tip of a pin), the convex lens L and another reference pin C are mounted on stands which can move by the side of the scale of an optical bench and their heights are adjusted so that the tips of O and C and also the centre of the lens L are in one straight line parallel to the bench. The position of C is adjusted for three times until there is no parallax between its tip and the tip of the real image of the object pin O, formed by the lens L. The positions of C are noted from the bench scale and let the mean of these three readings be (C). The position of the lens is also noted from the scale and let this reading be (L). The apparent distance between the lens and the reference pin is $(L \sim C)$. The correct value of LC is $(L \sim C) + \lambda_1$, where λ_1 is the index error between the lens L and the reference pin C.

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*The experiment can also be conveniently performed by moving the stands with the index mark on them, by the side of a metre scale fixed at one of the longer sides of the working table.

(*ii*) The convex mirror P is now placed on another stand between L and C and its position is adjusted three times until the rays reflected from the mirror form an image I coincident with the object pin O, and having no parallax between them. The three positions of the mirror are noted from the scale and let the mean of these three readings by (P). The apparent distance between the lens and the mirror is $(L \sim P)$ while the correct value of LP is $(L \sim P) + \lambda_2$, where λ_2 is the index error between the lens and the mirror.

(*iii*) The operations (*i*) and (*ii*) are repeated for 3 or 4 different positions of the lens.

(*iv*) The index errors λ_1 (between the lens and the reference pin) and λ_2 (between the lens and mirror) are determined in the usual way.

Experimental data :

(A). *To find index errors* λ_1 *and* λ_2 :—

TABLE I

Length of index rod in cm. (l)	Diff. of bench-scale readings when the two ends of index rod touch the,		Index errors in cm. for.	
	lens L and the reference pin C (d_1)	lens L and the pole P of the mirror (d_2)	LC is, $\lambda_1=(l-d_1)$	LP is, $\lambda_2=(l-d_2)$
$l=$... cm.	$d_1=(...)-(...)$ =...cm.	$d_2=(...)-(...)$ =...cm.	$\lambda_1=(...)-(...)$ =...cm.	$\lambda_2=(...)-(...)$ =...cm.

(B). *Record of the positions of lens, mirror, and reference pin* :—

TABLE II

No. of obs.	Positions in cm. of,		Mean (C) in cm.	Mirror positions in cm. (*P*)	Mean (*P*) in cm.	Corrected distances in cm. of,		Focal length in cm. is, $f=\frac{LC-LP}{2}$	Mean f in cm.
	lens (*L*)	referenee pin (*C*)				$LC=(L\sim C)+\lambda_1$	$LP=(L\sim P)+\lambda_2$		
		...		...					
1	...	...	...	...	...	...	...	...	
		...		...					
		...		...					
2	...	...	...	...	...	...	...	...	
		...		...					...
		...		...					
3	...	...	...	...	...	...	....	...	
		...		...					
		...		...					
4	...	...	...	...	...	...	...	...	
		...		...					

Precautions : (*i*) The image *C* due to the convex lens must be at an appreciable distance from the lens so that *LC* is large enough to be greater than the radius *PC* of the mirror. For this purpose, the object *O* should be placed slightly beyond the first focus of the lens *L*.

(*ii*) For accurate measurement, the apertures of lens and mirror should be reduced by stops.

Oral Questions and their Answers

1. Define focal length of a convex mirror and state whether its sign is $+ve$ or $-ve$.

A pencil or rays incident on the mirror in a direction parallel to the axis, after reflection will appear to diverge from a point which is called the focus of the mirror. The distance of this focus from the pole of the mirror is called focal length. The focal length of a convex mirror is $-ve$ while that of a concave mirror is $+ve$.

2. Can this mirror form a real image of a real object ?

No ; the image produced is virtual, diminished, erect with respect to the object and is formed behind the mirror at a distance which is less than the focal length f of the mirror.

3. Under what condition an object will be found to be coincident with its own image formed by reflection from the mirror ?

When the rays from the object after refraction through the lens are incident on the mirror normally.

4. Why do you require an additional convex lens for your experiment ?

The centre of curvature of the mirror is situated behind the mirror. Hence the rays incident on the mirror will be normal to the mirror (to get reflection in the same path) provided the rays are convergent and are going to converge at the centre of curvature of the mirror. The divergent rays from the object O can be made convergent by the convex lens and hence its requirement.

5. Can this arrangement be employed to determine the focal length of the convex lens employed ?

Yes ; By measuring the distances of O and C from the lens L we get the object distance (u) and image distance (v) of the lens. Putting these values of u and v (v is here $-ve$) with their proper signs in the formula, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$ we can calculate the focal length f of the lens.

6. What are the practical applications of the convex mirror ?

It is used as a driving mirror in motor car for its wide field of view. It is also used as a reflector in street lighting.

7. How can you distinguish this mirror from plane and concave mirrors ?

[See the answer of oral question 3 of Expt. 10, p. 50.]

8. Can you find the focal length of a concave mirror by this arrangement?

Yes; If the concave mirror be placed beyond C, where the lens L produces the real image, then the object O and its image, I will be seen coincident, when C is at the centre of curvature of the concave mirror. Half of the distance of C from the pole of concave mirror will give the focal length of the concave mirror.

12. Determination of the refractive index of the material of a convex lens by measuring its focal length and radii of curvature.

Theory: The focal length f of a lens is given by the formula,

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{r_1}-\frac{1}{r_2}\right) \qquad \dots \qquad \dots \qquad (1)$$

Here μ is the refractive index of the material of the lens and r_1 and r_2 are the radii of curvature of its first and second surfaces. For a double convex lens, both f and r_1 are negative and hence the relation (1) reduces to,

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{r_1}+\frac{1}{r_2}\right); \text{ or } \mu=1+\frac{r_1 r_2}{f(r_1+r_2)} \qquad \dots \qquad (2)$$

By measuring r_1, r_2 and f, and putting their *numerical* values in (2), we can find the value of μ.

The principle involved in the determination of f is, that if an object pin be placed at the first principal focus of the convex lens, then the emergent rays will be parallel. When these parallel rays fall normally on a plane mirror (on which the convex lens is placed) they will be reflected back in the same path and will form an image coincident with the object pin. The mean of the distances of the pin from the upper surfaces of the lens and the plane mirror will give the focal length of the lens.

Procedure: (*i*) The radii of curvature of the two surfaces of the lens are measured by a spherometer and thus we get r_1 and r_2.

(*ii*) In Fig. 14, the convex lens *L* is placed on a plane mirror *M* kept on the base *B* of a vertical stand *S*. On this vertical stand *S*, a pin *P* is fixed horizontally and it can be moved vertically up and down so that the line of movement of the tip *T* of the pin coincides with the principal axis of the lens. The height of the pin from the lens is adjusted until the tips of the pin and its image are coincident and there is no parallax between them. The heights f_1 and f_2 of the pin from the upper surfaces of the lens and the mirror are measured and the mean of these two heights gives the focal length f of the lens. This operation is repeated for two more times and the mean of these three values of f gives the focal length of the lens.

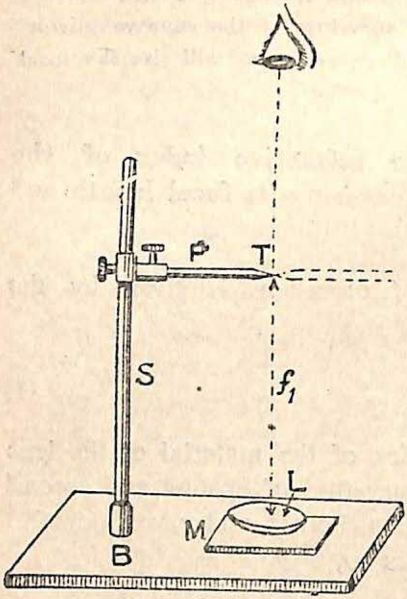

Fig. 14

(*iii*) Putting the numerical value of r_1, r_2 and f in the relation (2), μ of the lens is calculated.

Experimental data :

(A). *Determination of* r_1 *and* r_2 *by spherometer* :—

Value of each division of the linear scale $= s = \dots$ mm.

Pitch of the screw ... ... $= p = \dots$ mm.

Number of divisions on the circular scale $= N = \dots$

Least count of the instrument $= l.c. = p/N = \dots$ mm.

Distance between the outer legs $= d = \dfrac{\dots + \dots + \dots}{3} =$ cm.

TABLE I

No. of obs.	Surface of the lens	C.S. reading when the screw touches the lens surface (R_1)	When the screw touches the plate,			Total no. of cir. scale divs. rotated $=x=Nm+n$	Value of those divisions in mm. (h) $=x\times(l.c.)$	Mean h in cm.	Radius, $\left(r=\frac{d^2}{6h}+\frac{h}{2}\right)$ in cm.
			nos. of full rotation of the cir. disc (m)	final C.S. reading (R_2)	addl. no. of C.S. divs. rotated (n)				
1.	First	29	3	98	31	...	...		
2.	surface	...	...	...	...	...	...	...	$=...r_1$
3.	of lens	...	...	...	...	...	...		
1.	Second	...	...	...	...	...	...		
2.	surface	...	...	...	...	...	...	...	$...=r_2$
3.	of lens	...	...	...	...	...	...		

N.B. [For finding the value of *n*, additional number of circular scale divisions rotated, see Expt. 9(*a*), Part I.]

(B). *Determination of 'f' of the convex lens :—*

TABLE II

No. of obs.	Height of pin in cm. from the upper face of		Focal length $=f=\frac{f_1+f_2}{2}$cm.	Mean f in cm.
	lens (f_1)	mirror (f_2)		
1.	...	...	...	
2.	...	...	...	...
3.	...	...	...	

Calculations :

$$\mu=1+\frac{r_1r_2}{f(r_1+r_2)}=1+\quad\cdots\quad=\quad\cdots$$

Precautions : (*i*) To find the coincidence of the object pin with its real inverted image, parallax should be carefully avoided.

(*ii*) The pin should be moved along the axis of the lens so that the refraction may occur through the central part of the lens by which spherical and chromatic aberrations will be avoided.

Oral Questions and their Answers

1—4 [Same as in Expt. 4.]

5. Define refractive index ; does its value depend on the colour of light ?

If i and r are respectively the angles of incidence and refraction of a ray of light of wavelength λ, then for any ray, excepting the normal ray, $\frac{\sin i}{\sin r}=\mu$ (constant) which is defined as the refractive index of refracting medium with respect to the incident medium. Yes. $\mu_v > \mu_r$ *i.e.* μ increases as the wavelength of light decreases.

6. What relation does the velocities of light bear to the refrective index ?

If V_0 and V are the velocities of light in the incident and refracting media, then $\mu=\frac{V_0}{V}$.

7. Can you perform the experiment by using a concave lens ?

No ; for this lens cannot produce any real image and its first focus is on the negative side of the lens.

8. What is parallax and how would you avoid it ?

If the two objects are not coincident, then the movement of eye will cause a relative displacement between the two objects. This is parallax. When there is no relative displacement between the two objects with the movement of eye, then parallax is avoided [see Art. 2(*a*)].

13. Determination of the refractive index of a liquid by using a plane mirror and a convex lens.

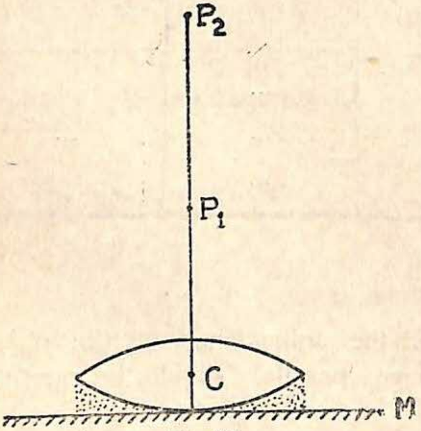

Fig. 15

Theory : If a double convex lens C of focal length f_1, be placed over a few drops of liquid placed on a plane mirror, then a plano-concave liquid lens of focal length f_2 is formed between the lower surface of the convex lens and the plane mirror [Fig. 15]. If F be the focal length of the combination (which is behaving as a convex lens), then we have $\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}$ ... (1)

Correcting for signs of F and f_1 which are both negative we get,

$$-\frac{1}{F}=-\frac{1}{f_1}+\frac{1}{f_2}$$

$$\text{or, } \frac{1}{f_2}=\frac{1}{f_1}-\frac{1}{F}=\frac{F-f_1}{Ff_1} \quad \dots \quad \dots \quad (2)$$

Finding f_1 and F experimentally by coincidence method, and putting their *numerical* values in the relation (2) we can calculate $1/f_2$. Again, the focal length f_2 of the plano-concave liquid lens is given by,

$$\frac{1}{f_2}=(\mu-1)\left(\frac{1}{r}-\frac{1}{r'}\right)=(\mu-1)\frac{1}{r} \quad [\because r'=\infty]$$

$$\text{or} \quad \mu=1+\frac{r}{f_2} \quad \dots \quad \dots \quad \dots \quad \dots \quad (3)$$

Finding r, the radius of curvature of the lower surface of the convex lens, by a spherometer and finding $1/f_2$ from the relation (2), we can calculate μ, the refractive index of the liquid.

Procedure : (*i*) The thickness t of the lens (thin equi-convex) at its centre, *i.e.* maximum thickness is measured by a slide callipers and $t/2$ is found out.

(*ii*) The radius of curvature of one surface of the convex lens (which is somehow kept marked) is determined by a spherometer. Thus we get r.

(*iii*) The convex lens C is then placed on a plane mirror M [Fig. 15] so that its particular surface, whose radius of curvature was measured, may touch the mirror. A horizontal pointer is moved vertically up and down along the axis of the lens until there is no parallax between the tip of the pin and its own real image formed by reflection, from the plane mirror, of the beam of parallel rays emerging out of the lens [Fig. 14]. Thus the pin is at the first principal focus P_1 of the lens [Fig. 15]. The distance h_1 of the pin P_1 from the upper surface of the lens is measured by a scale and half of the thickness t of the lens is added to h_1, when we get the focal length f_1 of the convex lens alone. This is repeated for three times and the mean of these three values gives f_1.

(*iv*) A few drops of liquid are now placed on the plane mirror and the surface of the lens, which was originally in contact with the mirror, is now placed over the liquid. The mean of the three values of the focal length F of the combination is then determined exactly in the same way as in (*iii*). This time the pointer and its real image will coincide at P_2 [Fig. 15] which is the first focus of the combination.

(*v*) By putting the mean *numerical values* of F and f_1 in (2), we get $1/f_2$. Then by putting the values of r and $1/f_2$ in (3), we can calculate μ.

Experimental data :

(A). *Thickness (t) of the lens at its centre by slide callipers :—*

TABLE I

[Make a table as in the case of slide callipers given in Expt. 10, Part I and take *at least* 4 observations.]

(B). *Determination of the radius of curvature (r) of that surface of the lens which is in contact with the mirror :—*

TABLE II

[Make a table as in the case of a spherometer given in Expt. 9(*a*) Part I.]

(C). *Focal length determination :—*

TABLE III

No. of obs.	Dist. of the pin from the upper face of convex lens in cm. (h_1)	Mean h_1 in cm.	Focal length of convex lens in cm. $f_1=h_1+\frac{t}{2}$	Dist. of the pin from the upper face of compound lens in cm. (h_2)	Mean h_2 in cm.	Focal length of compound lens in cm. $F=h_2+\frac{t}{2}$	μ of liquid
1.	...			...			
2.	...	...	(...)+(...) =...	...	...	(...)+(...) =...	...
3.	...			...			

Calculations :

From (2) we get,

$$f_2 = \frac{Ff_1}{F-f_1} = \cdots = \cdots \text{ cm.}$$

$$\mu = 1 + \frac{r}{f_2} = \cdots = \cdots$$

Precautions : [same as in Expt. 12.]

Oral Questions and their Answers

1—4. [Same as in Expt. 4.]

5—8. [Same as in Expt. 12.]

9. What is the nature of the liquid lens ?—It is a plano-concave lens.

10. Do you consider the focal length of the liquid concave lens greater or smaller than that of the convex lens ?

Greater (or smaller diverging power) otherwise the combination cannot behave as a convex lens having the first principal focus on the positive side.

11. Can you measure refractive index of any value by this method ?

No, when the refractive index of the liquid is such that the focal lengths f_2 and f_1 of the liquid concave lens and the given convex lens respectively are equal, the combination is no longer a lens and the method fails. If an equiconvex lens of refractive index μ $(=1{\cdot}5)$ be taken, then its focal length f_1 is equal to the radius r of its surfaces. The maximum refractive index of liquid is $\mu = 1 + \frac{r}{f_2} = 1 + \frac{r}{r} = 2$ (for $f_2 = f_1 = r$).

12. Can you find the refractive index of the given liquid without using a spherometer ?

Yes ; by repeating the experiment with a liquid of known refractive index (μ'), the focal length f_2' of the liquid concave lens is found out. The radius r of the lower surface of lens is then found out from the relation $\mu' = 1 + \frac{r}{f_2'}$; or $r = (\mu' - 1)\, f_2'$. Hence the refractive index of the given liquid is given by, $\mu = 1 + \frac{f_2'}{f_2}(\mu' - 1)$; or $\frac{\mu - 1}{\mu' - 1} = \frac{f_2'}{f_2}$.

14. Travelling vernier microscope.

There are various forms of travelling microscopes one of which is shown in Fig. 16.

This is an ordinary compound microscope M capable of both vertical and horizontal movements and its axis can also be kept vertical, inclined or horizontal. The microscope can slide along a vertical pillar provided with a scale S_2. It can be clamped at any position of the pillar by a screw and by another, screw a slow motion can be imparted. As the microscope moves a vernier V_2 attached to the microscope moves over the scale. By this vernier (V_2) and scale (S_2), the vertical displacement of the microscope can be obtained.

The vertical pillar containing the microscope can slide within a groove made on a horizontal metal base provided with two levelling screws and a spirit level over the base. There is another vernier V_1 attached to the pillar and as the pillar moves horizontally, the vernier V_1 moves over a horizontal

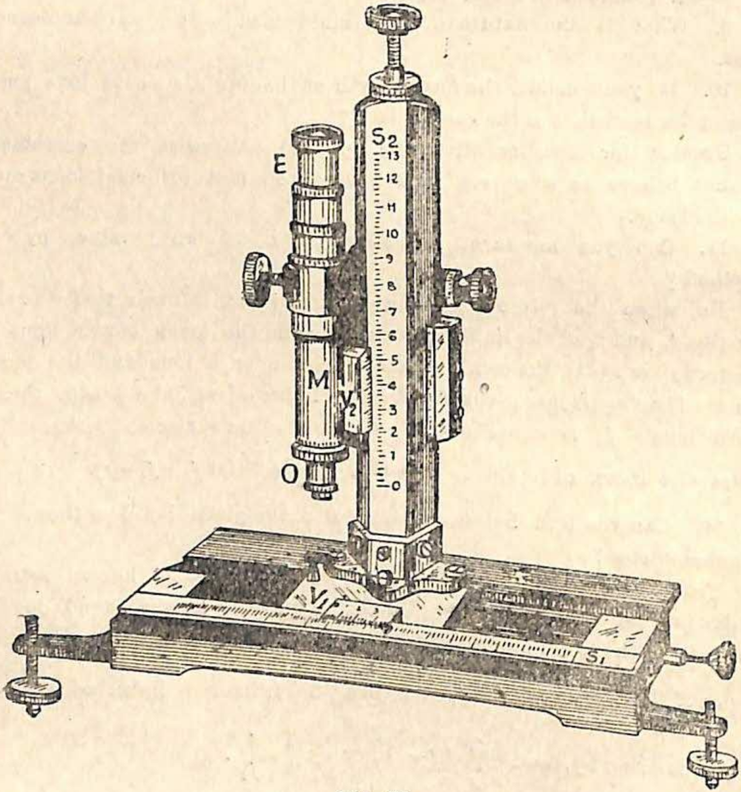

Fig. 16

scale S_1 on the base. Thus by this scale (S_1) and vernier (V_1), the horizontal displacement of the microscope can be obtained. The pillar can be kept clamped by a screw at its any position on the horizontal base and by another screw slow motion can be imparted.

The microscope contains a cross-wire which should be sharply focussed by moving the eye-piece E. The microscope should be moved as a whole to focus an object in front of the objective O and adjustments are to be made so that there is no parallax between the cross-wire and the image of the object to be seen.

15. Determination of the refractive index of a transparent substance by using a travelling vernier microscope

(a) For a transparent liquid.

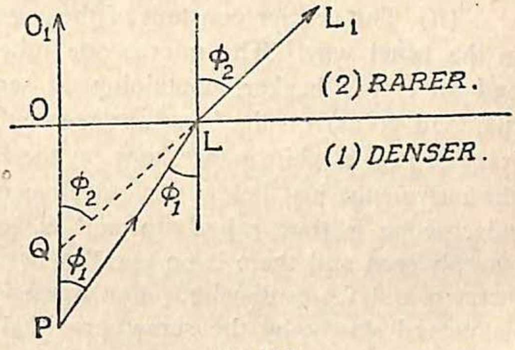

Fig. 17

Theory : The normal ray PO and an oblique ray PL proceeding from an object P, placed in the denser medium of refractive index μ_1 are incident on the surface of a rarer medium of refractive index μ_2. The emergent rays OO_1, and LL_1 when produced backwards meet at Q which is the virtual image of P. Hence the object distance is $u=OP$ while the image distance is $v=OQ$.

For refraction at L, ϕ_1 and ϕ_2 are the angles of incidence and refraction and hence, $\mu_1 \sin \phi_1=\mu_2 \sin \phi_2$. When viewed normally ϕ_1 and ϕ_2 are very small and hence, we may write

$$\mu_1 \tan \phi_1=\mu_2 \tan \phi_2$$

$$\text{or, } \mu_1 \frac{OL}{OP} = \mu_2 \frac{OL}{OQ}$$

$$\text{or, } \frac{\mu_1}{u} = \frac{\mu_2}{v}.$$

If the rarer medium is air, ($\mu_2 = 1$) and the denser medium has the refractive index, μ, then. $\frac{\mu}{u} = \frac{1}{v}$; or, $\mu = \frac{u}{v}$.

$$\text{or, } \mu = \frac{\text{real depth}}{\text{apparent depth}} \quad \cdots \quad \cdots \quad (1)$$

The formula (1) is employed to find the refractive index μ of a transparent slab.

Procedure : (*i*) At first the base of the microscope is made horizontal by the help of the spirit level and the two levelling screws. The eye-piece is then sharply focussed on the cross-wire and the microscope tube is fixed vertical.

(*ii*) The vernier constant of the *vertical scale* is determined in the usual way. The microscope tube is raised up vertically and an empty beaker, containing a scratch mark (made by diamond point) on the *inner surface* of the bottom of the beaker is placed on a white paper kept on the horizontal metal base of the instrument just below the objective of the microscope. The microscope is then raised up and down until the scratch is sharply seen and there is no parallax between the image of the scratch and the cross-wire. For sharp focussing, the microscope is moved slowly by the screw provided for this purpose. The reading of the vernier on the vertical scale is noted and this is repeated independently for three times and the mean of these three readings gives the first reading (R_1).

(*iii*) The microscope is raised a little and some quantity of liquid is poured in the beaker without disturbing its position. The *image* of the scratch is again sharply focussed by avoiding parallax and the reading of the vernier on the vertical scale is noted and this is also repeated independently for three times. The mean value of these three readings is the second reading (R_2).

(*iv*) To focus the liquid surface, some lycopodium powders or cork dusts are *thinly* scattered on the surface and the microscope is focussed on this powder and the mean of three independent readings of the vernier from the vertical scale gives the third reading (R_3).

(*v*) The real depth of the liquid is, $u=(R_3 \sim R_1)$ while its apparent depth is, $v=(R_3 \sim R_2)$. Hence, the refractive index of the liquid is determined from the formula (1).

(*vi*) The experiment is repeated for two other depths* of the liquid and for each depth μ is calculated. The mean of these three values of μ gives the refractive index of the liquid.

Experimental data :

(A). *Vernier constant of vertical scale* :—

Smallest division of vertical scale=...mm=...cm.

... v.d. = ... s.d. ; or, 1 v.d.=...s.d.

$\therefore$ Vernier constant $(v.c.)=(1 \text{ s.d.}-1 \text{ v.d.})=(\ldots-\ldots)=$ ...cm.

(B). *Readings for the scratch when the beaker is empty* :—

TABLE I

Reading in cm. of the,			Mean R_1 in cm.
Scale (S)	Vernier $V=(v.r.)\times(v.c.)$	Total reading $=R_1=(S+V.)$	
...	(...)×(...)=...	...	...
...	(...)×(...)=...	...	
...	(...)×(...)=...	...	

---

*The maximum depth of the liquid *should not exceed* the focal length of the microscope objective. If the focal length of the objective be 2·5," then the depths of the liquid should be nearly 1", 1·5" and 2".

(C). *Readings for image and liquid surface :—*

TABLE II

Liquid depth	Readings for *image* in cm. of				Readings for *surface* in cm. of,				$u=(R_3 \sim R_1)$ in cm.	$v=(R_3 \sim R_2)$ in cm.	$\mu=\frac{u}{v}$	Mean μ
	Scale (S)	Vernier $V=(v.r.)\times(v.c.)$	Total $=R_2$ (S+V)	Mean R_2	Scale (S)	Vernier $V=(v.r.)\times(v.c.)$	Total $=R_3$ $=(S+V.)$	Mean R_3				
Small	...	(...)×(...)	...	...	...	(...)×(...)	...	...	...	...	...	
	...	(...)×(....)	...		...	(...)×(...)	...					
	...	(...)×(...)	...		...	(...)×(...)	...					
Medium	...	...	...	...	...	...	...	...	...	...	...	...
	...	....	...		...	...	...					
	...	...	...		...	...	...					
Big	...	...	...	...	...	...	...	...	...	...	...	
	...	...	...		...	...	...					
	...	...	...		...	...	...					

Calculation :

(*i*) $\mu = u/v = \cdots = \cdots$

(*ii*) $\mu = \cdots = \cdots = \cdots$

(*iii*) $\mu = \cdots = \cdots = \cdots$

(b) For transparent plate.

Theory : [Same as in the part (*a*) of this Expt.]

Procedure : (*i*) Same as the operations (*i*) of 'procedure' of the part (*a*) of this Expt.]

(*ii*) The vernier constant of the vertical scale is determined in the usual way. A white paper with an ink mark on it is attached to the horizontal metal base of the microscope. The objective of microscope is brought very close to the ink mark and the microscope tube is raised vertically until the ink mark is sharply focussed. The microscope tube is then raised or lowered slowly by the screw provided for this purpose, until there is no parallax between the cross-wire and the image of the ink mark. The reading of the vertical scale and vernier is noted. This focussing and recording of the readings of the vertical scale are repeated thrice. The mean of these three independent readings gives the first reading (R_1).

(*iii*) The microscope is then raised a little and the transparent slab, whose refractive index is required, is placed on the ink mark. The image of the mark is found to be elevated and this *image* due to the slab is again sharply focussed by the microscope by avoiding parallax. This focussing is done independently for three times and in each case the readings of the vertical scale are noted. The mean of these three readings gives the second reading (R_2).

(*iv*) To focus the surface of the transparent slab, some lycopodium powders or cork dusts are *thinly* scattered on the surface. The microscope tube is again raised to focus these powders sharply. This focussing is done independently for three times and in each case, the readings of the vertical scale are noted. The mean of these three readings gives the third reading (R_3).

(*v*) The real thickness of the slab is given by, $u=(R_3 \sim R_1)$ while its apparent thickness is given by, $v=(R_3 \sim R_2)$. The refractive index (μ) of the given solid is then calculated by the relation $\mu=u/v$.

(*vi*) The experiment may be repeated for two other slabs of different thicknesses* and the mean value of μ is determined, provided the material of these plates are same.

Experimental data :

(A). *Vernier constant of the vertical scale* :—

[Same as that in the part (a) of this Expt.].

---

*The maximum thickness of the slab should not exceed the focal length of microscope objective, *e.g.* if the focal length of the objective be 2·5″ then the thickness of the slab should be nearly 1″, 1·5″ and 2″.

(B). *Readings for the ink mark without the slab* :—

TABLE I

[Same as in part (*a*) of this Expt.]

(C). *Readings for the image and the surface of solid* :—

TABLE II

Thickness of slab	Readings for ink-mark image with slab in cm. of.				Readings for solid surface in cm. of,				$u=(R_3 \sim R_1)$ in cm.	$v=(R_3 \sim R_2)$ in cm.	$\mu=\frac{u}{v}$	Mean μ
	Scale (S)	Vernier $V=(v.r.)\times(v.c)$	Total $=(R_2)=(S+V)$	Mean R_2	Scale (S)	Vernier $V=(v.r.)\times(v.c.)$	Total $=R_3=(S+V.)$	Mean R_3				
	...	...	...		...	...	...					
Small	...	...	...	...	...	...	...	...	....	...	...	
	...	...	...		...	...	...					
	...	...	...		...	...	...					
Medium	...	...	...	...	...	...	...	..	...	...	..	...
	...	...	...		...	...	...					
	...	...	...		...	...	....					
Big.	...	...	...	...	...	...	...	...	...	...	...	
	...	...	...		...	...	...					

Calculations :

$\mu = u/v =$ ... = ...

etc. etc. etc.

Precautions : (*i*) The microscope tube is to be kept *vertical*.

(*ii*) Lycopodium powders or cork dusts (when lycopodium sinks or goes into solution, in the liquid) are to be *scattered very thinly* over the liquid or solid surface.

(*iii*) The parallax between the cross-wire and the image should be avoided in each case.

(*iv*) The greatest thickness of the liquid or solid *must not exceed* the focal length of the microscope.

(*v*) A piece of white paper is to be placed underneath the substance to have a brighter field of view.

Oral Questions and their Answers

1. Why do you make a scartch on the upper face of the bottom of the beaker ?

In that case, real thickness of the liquid will be equal to the distance between the scratch and the free surface of liquid which is equal to the difference between third and first readings.

2. Can you find μ of liquid by giving a scratch at the lower face of the bottom of the beaker.

Yes ; in that case 4 mircroscope-readings are necessary. The beaker should already contain the liquid and the readings R_1 and R_2 for the image and the liquid surface are respectively noted. Some additional liquid is taken in the beaker and again the readings R_3 and R_4 for the new image and the new liquid surface are respectively noted. Elevation of the image is $e=(R_3 \sim R_1)$ due to the addition of a liquid of thickness $t=(R_4 \sim R_2)$. Then, $\mu=t/(t-e)$.

3. Will you get accurate result, if greater thickness of liquid be taken ?

Yes ; for both the elevation of the image and the thickness of the liquid will be greater and hence the error in measurement will be less. But the *maximum liquid thickness should not be greater than the focal length of the microscope-objective*.

4. Is this method suitable for a volatile liquid ?

No ; for the liquid-thickness will decrease during experiment, due to evaporation of the liquid.

5—6. [Same as Expt. 12.]

7. What is the nature of the objective and the eye-piece of microscope and what type of image is produced by each ?

The microscope objective is a convex lens of short focal length and it produces real, magnified and inverted image. The eye-piece is also a convex lens of focal length comparatively longer than that of the objective and produces virtual, magnified and erect image at the least distance of distinct vision. Thus the final image is virtual and inverted with respect to original object.

8. [Same as in Expt. 12]

9. Can this method be employed to find the refractive index of a transparent solid ? Yes ; [see part (*b*) of Expt. 15].

16. Spectrometer and its Adjustments.

Description :– The table spectrometer which is commonly employed in the laboratory is shown in Fig. 18 and has the following parts :—

(i) Prism table (P)— It is a small circular table mounted on a vertical stand so that it can be raised or lowered or can be clamped at any position by the screw *S′*. It is provided with three levelling screws *E*, *F* and *G* which are shown separately in Fig. 19. On the surface of the table there are straight lines marked parallel and perpendicular to the line joining the screws *E* and *F* (shown in Fig. 19). There are also concentric circles, the common centre of which coincides with the centre of the table. *The table can be rotated about a vertical axis which should coincide with the vertical axis of the instrument* . The angle of rotation of the prism table

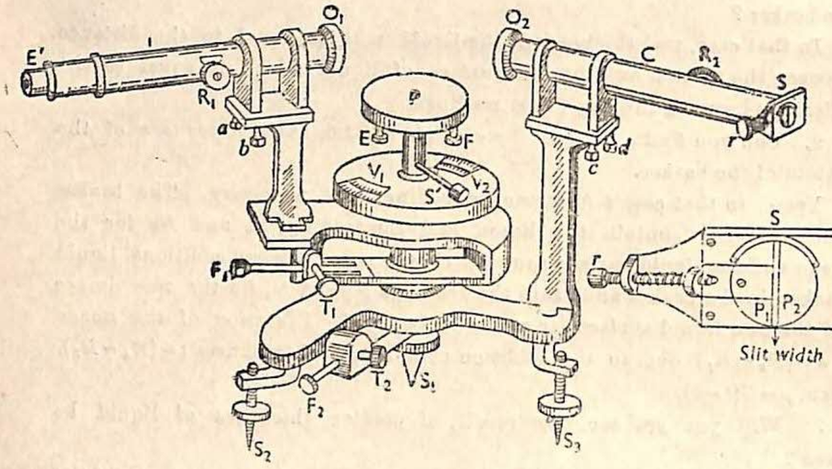

Fig. 18

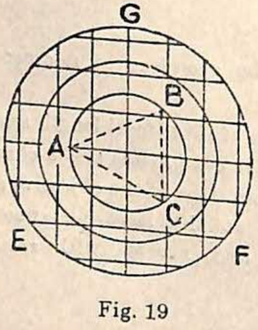

Fig. 19

can be recorded by two verniers V_1 and V_2, which can rotate with the table over a circular scale (graduated in half degrees). The table can be fixed by a screw F_2 and a smaller rotation can be imparted to it by a tangent screw T_2.

(ii) Collimator (C)— This is a horizontal tube at one end of which there is a convex lens O_2 while at the other end there is an adjustable narrow slit S which can be taken in or out of the tube by rack and pinion arrangement R_2 [magnified arrangement of slit is shown separately in the side figure]. *The axis of the collimator should be perpendicular to the vertical axis about which the prism table can ratate.* The collimator can be tilted by screws c and d below it.

(iii) Telescope (T)— It is a small astronomical telescope provided with a compound eye-piece and a cross-wire. *The axis of the telescope should also be horizontal and perpendicular to the vertical axis of rotation of the prism table.* It can be rotated about the vertical axis of the instrument and the angle of rotation can be recorded with the help of two verniers V_1 and V_2, from a scale (graduated in half degrees) which moves with the rotation of the telescope. For recording the readings of the scale, these two verniers are kept at 180° apart. The telescope can also be tilted by screws a and b. The whole apparatus is supported on a base, provided with three levelling screws S_1, S_2 and S_3. The telescope can be fixed by the screw F_1 while a slow motion can be imparted to it by a tangent screw T_1.

Adjustments : The following adjustments are necessary to work with the spectrometer :—

(*a*) The axis of the instrument should be made vertical, by making it to coincide with the vertical axis of rotation of the prism table.

(*b*) The axes of the telescope and the collimator should be made horizontal and perpendicular to the axis of the instrument.

(*c*) The refracting faces of the prism should be made vertical *i.e.* parallel to the axis of rotation of the telescope.

(*d*) The telescope and the collimator should be adjusted for parallel rays.

(a) & (b)—Levelling of telescope and collimator :

(*i*) A spirit level is placed above the telescope tube T and the length of the telescope tube is made parallel to the line joining the two base screws S_1 and S_2 and kept by the side of the screw S_2. The bubble of the spirit level is brought at the centre by turning the base screw S_2 only, which is on the side of the telescope.

(*ii*) The telescope is now rotated by 180° so that it now comes to the side of the other base screw S_1. The bubble is now brought at the centre, half by rotating the screw S_1 and half by tilting the telescope tube by the screws a and b.

(*iii*) The telescope is again brought towards the side of the screw S_2 and the operation (*i*) is repeated. By rotating the telescope by 180°, it is again brought to the side of the screw S_1 and the operation (*ii*) is repeated. If the operations (*i*) and (*ii*) are repeated several times alternately, then the bubble will remain at the centre for both the positions of the telescope.

(*iv*) The telescope is then brought parallel to the third screw S_3 which is on the perpendicular drawn to the line joining the screws S_2 and S_1. Now this third screw S_3 is alone altered, once only, until the bubble comes at the centre. When there is no third screw, then for this position of the telescope the two screws S_2 and S_1 are to be *adjusted equally* to bring the bubble at the centre. At this time, the bubble will remain at the centre for all positions of the telescope. Thus the axis of the telescope is now horizontal and the axis about which it rotates is made vertical.

(*v*) The slit is now illuminated by sodium light and the image of the slit is observed by the telescope. If the image of the slit is not at the middle of the field, the screws c and d below the collimator are to be adjusted to bring the image at the centre of the field.

Now the axes of both the telescope and collimator become horizontal and the axis of the instrument about which the telescope and the prism table rotate becomes vertical.

(c)—Levelling of prism table :

(*i*) *By spirit level* :—For this adjustment, the spirit level is placed at the centre of prism table with its length parallel to *EF* [Fig. 19], the line joining the two screws *E* and *F*. The two screws are then adjusted equally in the opposite directions to bring the bubble at the centre. The spirit level (placed at the centre of the table) is then brought perpendicular to the line *EF* and the third screw *G* is alone adjusted to bring the bubble at the centre. Thus the prism table is now horizontal. If the bottom face of the prism, which is placed on the prism table, is perpendicular to its three edges, then by this adjustment alone, the refracting faces of the prism would be vertical. But actually slight difference may remain which may be eliminated by optical levelling as described below.

(*ii*) *By optical method* :—The slit is illuminated by sodium light and the telescope is turned so that its axis makes an angle of *about* 90° with the axis of the collimator. The prism is now placed on the prism table in such a way that the centre of the prism may coincide with that of the prism table and one of the faces (say the face *BC*) of the prism *ABC* becomes perpendicular to the line joining the two screws *E* and *F* attached to the prism table [Fig. 19]. The prism table is then rotated until the light reflected from this face *BC* of the prism enters the telescope. If the image of the slit is not at the centre of the field of the telescope, the screws *E* and *F* are turned equally in the opposite directions to bring the image at the centre of the field. The prism table is then rotated until the light reflected from the other face of the prism enters the telescope. This time only the third screw *G* is rotated to bring the image at the middle region of the field.

Now the refracting faces of the prism become vertical and parallel to the axis of rotation of the telescope.

(d)—Schuster's method of focussing the telescope and collimator for parallel rays :

The best method of focussing the telescope and the collimator for parallel rays within the dark room is by Schuster's method.

(*i*) The telescope is directed towards a white surface or towards an electric lamp and the cross-wire is sharply focussed by moving the focussing lens in or out.

(*ii*) The slit is illuminated by sodium light, and the prism table, on which the prism is placed with its centre coinciding with the centre of the table, is rotated until one of the refracting faces of the prism (AB) [Fig. 22] is directed towards the collimator. On looking through the other face (AC) of the prism and towards its base, the image of the slit formed by the prism will be seen by the naked eye. The prism table is then rotated in a proper direction until this image of the slit, as seen by the naked eye, approaches as near to the direct path of the rays from the collimator as possible. The telescope is now brought to this position of the eye to receive the image. This is the approximate position of minimum deviation and at this position of the prism, the image of the slit will go away from the direct path of the rays in whatever direction the prism table is rotated. Now the telescope is slightly rotated from this position, in a direction away from the direct path of rays, so that the deviation of the rays entering the telescope will now be greater than minimum. For this position of the telescope, the image of the slit can be obtained within the telescope for *two positions* of the prism. In one position, the angle of incidence on the prism will be greater than that for minimum deviation and is known as the **Slanting position**. In another position of the prism (obtained by rotating the prism table in a direction opposite to the former position), the angle of incidence on the prism will be less than that for minimum deviation and is known as the **Normal position.**

(*iii*) The prism is now taken to the *slanting position* to bring the image within the telescope, and the *eye-piece* of the *telescope is adjusted* by rack and pinion arrangement until the image is sharply focussed by the telescope. This time the *image is very narrow*.

(*iv*) The prism is taken to the *normal position* to bring the image within the telescope, and the position of the *slit is adjusted* by rack and pinion arrangement until the image is very sharp. This time the *image is very wide*.

Again the operation (*iii*) and then the operation (*iv*) are repeated in order and if such repetitions are made several times, then the image will remain sharp for both positions of the prism. The telescope and the collimator are now adjusted for parallel rays.

Theory of Schuster's method of Focussing :—

For a small pencil of rays incident on a prism, the relation between the object distance u and the image distance v is given by,

$$v = u\frac{\cos^2 i_1}{\cos^2 r_1}\Big/\frac{\cos^2 i}{\cos^2 r} \qquad \ldots \qquad \ldots \quad (1)$$

Here, i & r=angles of incidence and refraction at the first face, and r_1 & i_1=angles of incidence and emergence at the second face [see Art. 3. 19 ; Text Book On Light].

Operation I

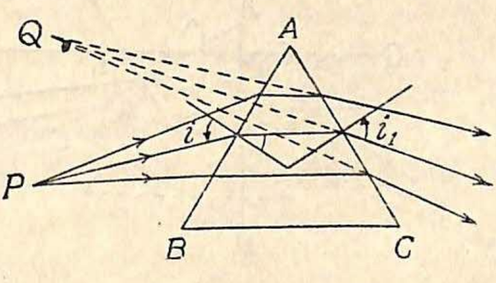

Fig. 20(*a*)

When the prism is brought to the position *ABC* of minimum deviation, [Fig. 20(*a*)] $i=i_1$ and $r=r_1$. Here it evident from (1) that $v=u$. Thus the object and image distances are equal [Fig. 20 (*a*)].

Operation II

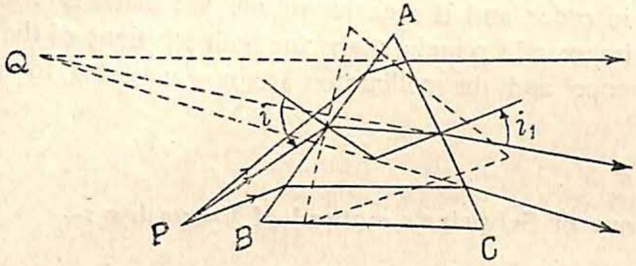

Fig. 20(*b*)

When the prism is rotated to the position *ABC* [Fig. 20(*b*)] to make $i>i_1$ (**Slanting position of the prism),**

$\frac{\cos^2 i}{\cos^2 r} < \frac{\cos^2 i_1}{\cos^2 r_1}$; and hence from (1) we get, $v>u$. Thus the image is formed at a longer distance from the prism [Fig. 20(*b*)]. If the telescope is focussed for this image, then it remains focussed for a longer distance.

Operation III

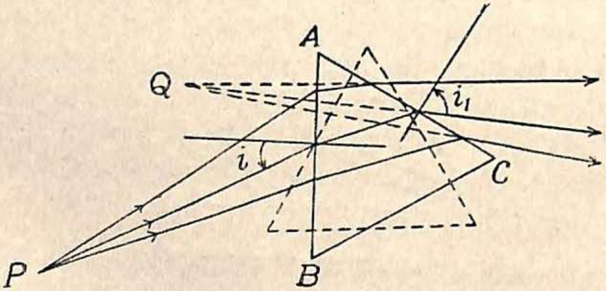

Fig. 20(*c*)

When the prism is rotated to the position *ABC* [Fig. 20(*c*)] to make $i<i_1$ (**Normal position of the prism),**

$\frac{\cos^2 i}{\cos^2 r} > \frac{\cos^2 i_1}{\cos^2 r_1}$ and hence from (1) we get $v<u$ [Fig. 20(*c*)].

Thus the image is formed nearer to the prism and consequently this image becomes out-focussed by the telescope which was previously focussed for the distant image at the slanting position of prism. If now the slit of the collimator is adjusted so that the image may again be sharply seen by the previously adjusted telescope, then by such adjustment of the slit, the image will be taken at a longer distance.

If now the operations II and III are alternately continued, then at each normal position of the prism the image is taken at a longer distance (by the adjustment of the position of the slit) to have the image clearly seen by the telescope already focussed for longer distance, while at the next slanting position of the prism, the telescope is adjusted to focus the image which is formed at the still more distant position. Thus the telescope will be gradually focussed for longer and longer distances until after a few repetitions of the above two operations alternately, the telescope will be focussed for infinity. The telescope and the collimator are now adjusted for parallel rays.

17. To determine the refractive index of a thick Prism by a Spectrometer.

Theory :—If D_m be the minimum deviation of a monochromatic ray of light refracted through the principal section of a prism of refracting angle A, then the refractive index of the material of the prism with respect to the surrounding air is given by,

$$\mu = \frac{\sin\frac{A+D_m}{2}}{\sin\frac{A}{2}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots (1)$$

The principle employed to measure A is, that when parallel rays from a collimator [Fig. 21] are reflected from the two faces AB and AC of the prism, the angle between these two reflected rays will be double the angle A of the prism. For, as the reflecting surface goes from AB to AC position by rotating by an angle A, the reflected ray must rotate by an angle $2A$. By measuring A and D_m we can find μ from (1).

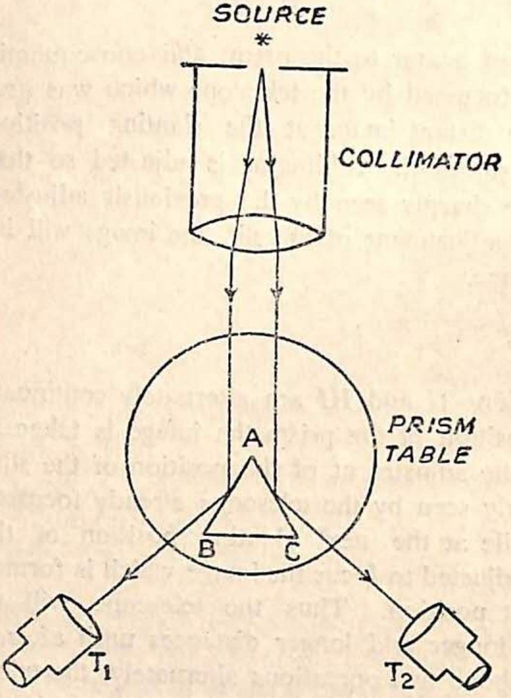

Fig. 21

Procedure : (*i*) By a spirit level, the axes of the telescope and the collimator are made horizontal and also perpendicular to the vertical axis of rotation of the prism table and the telescope [see 'adjustments (*a*) & (*b*)' of Art. 16, p. 72]. The prism table is also levelled by a spirit level to make its upper surface horizontal and if the bottom face of the prism is perpendicular to its edges, then the refracting faces of the prism will be vertical when it is placed on the prism table [see 'adjustment (*c*) (*i*)' of Art. 16, p. 73].

(*ii*) An asbestos ring soaked with common salt solution in water is held in the non-luminous part of a Bunsen flame, when the colour of the flame becomes golden yellow. The brightest part of this flame is held at a distance of about 6″ or 7″ from the slit which is made narrow and vertical.

(*iii*) The cross-wire in the eye-piece of the telescope is sharply focussed by moving the focussing lens in or out. The prism table is further levelled by optical method so that the refracting faces of the prism, when placed on the table, may be exactly vertical [see 'adjustment (*c*) (*ii*)' of Art. 16, p. 73]. Then the telescope and the collimator are focussed for parallel rays by Schuster's method [see 'adjustment (*d*)' of Art. 16, p. 73].

(*iv*) To find the angle A of the prism, at first the vernier constant of both the verniers is determined and the prism is placed on the prism table so that its edge A coincides with the centre of the table. The prism is placed in such a way that the vertical plane through the axis of the collimator will cut the base BC nearly normally [Fig. 21]. Parallel rays from the collimator now fall on both the faces AB and AC of the prism and after reflection, form images which can be seen by looking towards those faces. The image formed by reflection from the face AB of the prism is first seen by an unaided eye and then the telescope is taken to the position (T_1) of the eye to receive the image. The telescope is then moved slowly by the tangent screw until the centre of the cross-wire coincides with one edge (say right edge) of the slit image. The readings of both the verniers are noted and this is repeated for three independent settings of the telescope. The mean value of these three readings corresponding to each vernier is determined.

Next the reflected image formed by the reflection of rays, from the other face AC of the prism is first received by the unaided eye and then by the telescope taken at the position T_2. The entire operation, as in the case of first reflected image, is repeated by coinciding the centre of the cross-wire with the *same edge* of the slit image. Again the mean value of the three readings corresponding to each vernier is determined.

(*v*) The difference between the two mean readings of a vernier for the two positions of the telescope, (T_1 and T_2) is determined separately for the two verniers and the mean of these two differences when halved, gives us the angle A of the prism.

(*vi*) To find the minimum deviation D_m, the prism is placed on the prism table with one of its faces (AB) directed towards the collimator and the centre of the prism coinciding with the centre of the table [Fig. 22]. On looking through the other face (AC) of the prism and towards its base BC, we shall see the refracted image of the slit. The prism table is then rotated in a proper direction until this refracted image (as seen by the eye) approaches as near to the direct course of the rays (shown by dotted line) from the collimator, as possible. This position of the prism is its minimum position. The telescope is now brought to the position of the eye (position T_1 of Fig. 22) to make the centre of the cross-wire coincident with one edge (say right edge) of the slit image. The prism table is then rotated a bit by the tangent screw to displace the image by a very small amount in the direction of its decreasing deviation. The telescope is next rotated by the tangent screw attached to it so that the centre of the cross-wire may again coincide with the same edge of the slit image. These slow adjustments of the prism table and telescope are to be continued until the image *just begins to turn back*. At this time, the readings of both the verniers are noted for three different settings of the telescope for minimum deviation. The mean of the three readings corresponding to each vernier is determined.

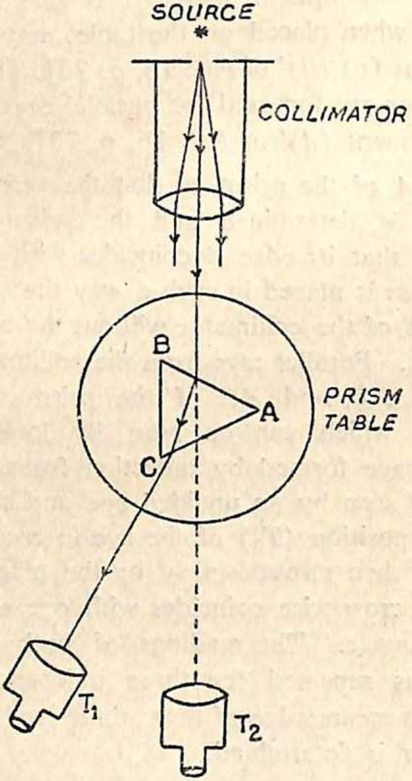

Fig. 22

(*vii*) The prism is now withdrawn and the direct light is received by the telescope (at the position T_2 of Fig. 22).

The centre of the cross-wire is made coincident with the *same edge* of the slit image as before and three readings are noted from each vernier for three independent settings of the telescope for direct rays. The mean of the three readings corresponding to each vernier is again found out.

(*viii*) The difference between the mean readings for the minimum deviated rays and direct rays is determined separately for each vernier and the mean of these two differences gives the minimum deviation D_m. Knowing A and D_m, μ can be calculated from the relation (1).

Experimental data :

(A). *Vernier constant of both verniers* :—

Smallest circular scale division $=(\frac{1}{2})^\circ$.

30 vernier divisions = 29 scale divisions.

$$\text{Vernier constant}=\left(1-\frac{29}{30}\right)\text{ s. d.}=\frac{1}{30}\text{ s.d.}=\left(\frac{1}{30}\times\frac{1}{2}\right)^\circ=1'.$$

(B). *To find A* :—

TABLE I

[Numerical figures given in the table are for illustrations only].

Vernier number	Readings for *first image*, of,				Readings for *second image*, of,				Difference θ	Mean θ	$A=\frac{\theta}{2}$
	Scale (S)	Vernier (V)	Total $=(S+V)$	Mean	Scale (S)	Vernier (V)	Total $=(S+V)$	Mean			
First	272°	25′	272°25′	$272°26'=R_1$	32°	13′	32°13′	$32°14'=R_2$	$[360-(R_1\sim R_2)]$ $=119°48'$	...	...
	...	26′	272°26′		...	14′	32°14′				
	...	27′	272°27′		...	15′	32°15′				
Second	...	...	...	$...=R_3$	...	...	...	$...=R_4$	$(=R_3\sim R_4)$ $=...$		
	...	...	...		...	...	...				
	...	...	...		...	...	...				

(C). *To find D_m .—*

TABLE II

[Numerical figures given in the table are for illustrations only].

Vernier number	Readings for the *minimum deviation*, of,				Readings for the *direct rays*, of,				Minimum deviation (D_m)	Mean D_m
	Scale (S)	Vernier (V)	Total=(S+V)	Mean	Scale (S)	Vernier (V)	Total=(S+V)	Mean		
First	280°30′	10′	280°40′	280°41′ = R_1	328°30′	4′	328°34′	328°35′ = R_2	$(R_1 \sim R_2)$ =47°54′	...
	...	11′	280°41′		...	5′	328°35′			
	...	12′	280°42′		...	5′	328°35′			
Second	...	...	...	... = R_3	...	...	...	... = R_4	$(R_3 \sim R_4)$ =...	
	...	...	....		...	...	....			
	...	...	...		...	....	...			

Calculations :

$$\mu = \frac{\sin\frac{A+D_m}{2}}{\sin\frac{A}{2}} = \frac{\sin\frac{(\cdots)+(\cdots)}{2}}{\sin\frac{\cdots}{2}} = \cdots$$

Precautions : (*i*) Some times the zero of the circular scale is crossed by the zero of the vernier when the vernier moves from one position to another. In this case the angle turned through is {360—(differences of the two vernier readings)} as is shown in Table I with the first vernier.

(ii) There should not be any parallax between the cross-wire and the slit image.

(*iii*) The vertical cross-wire or better the centre of the cross-wire should be made coincident with the same edge of slit image.

18. To draw a curve connecting the angle of incidence and the deviation of a ray through the prism with the help of a spectrometer and hence to find the minimum deviation and refractive index of prism.

Theory : Let a ray PQ be incident at an angle i on the principal section ABC of a thick prism [Fig.23]. A part of this ray will be reflected along QR while the rest will be refracted along QS and will then emerge along ST. The $\angle TOL$, between the deviated ray ST and the direct ray PQL, gives the deviation D of the ray. If the angle between the reflected ray QR and the direct ray PQL, viz. $\angle RQL$, be measured, then the angle of incidence $i = \frac{180° - \angle RQL}{2}$.

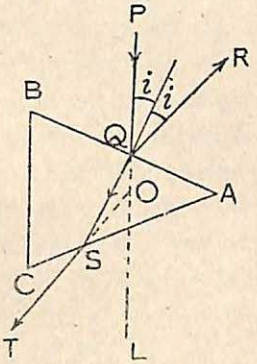

Fig. 23

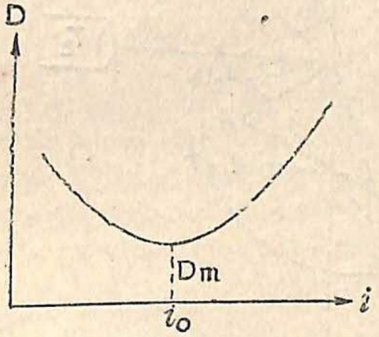

Fig. 24

The deviation D will vary with the angle of incidence. If a graph be drawn by plotting D against i then we shall get a curve as shown in Fig. 24. At a particular angle of incidence i_0, the deviation will assume a minimum value D_m which can be obtained from graph. If the angle A of the prism be known then by knowing D_m from the $(i-D)$ curve, the refractive index μ of the material of the prism can be found out from the relation,

$$\mu = \frac{\sin (A + D_m)/2}{\sin A/2} \quad \ldots \quad \ldots \ (1)$$

Procedure : (*i*) The slit of the spectrometer is illuminated by sodium light and it (spectrometer) is levelled and focussed for parallel rays by Schuster's method [for details, see adjustments (*a*), (*b*), (*c*) and (*d*) of Art. 16 on p. 72 & 73]. The vernier constants of both the verniers are determined.

(*ii*) The prism table can be made fixed or free to the scale or vernier by making the screw *S′* [see Fig. 18] tight or loose

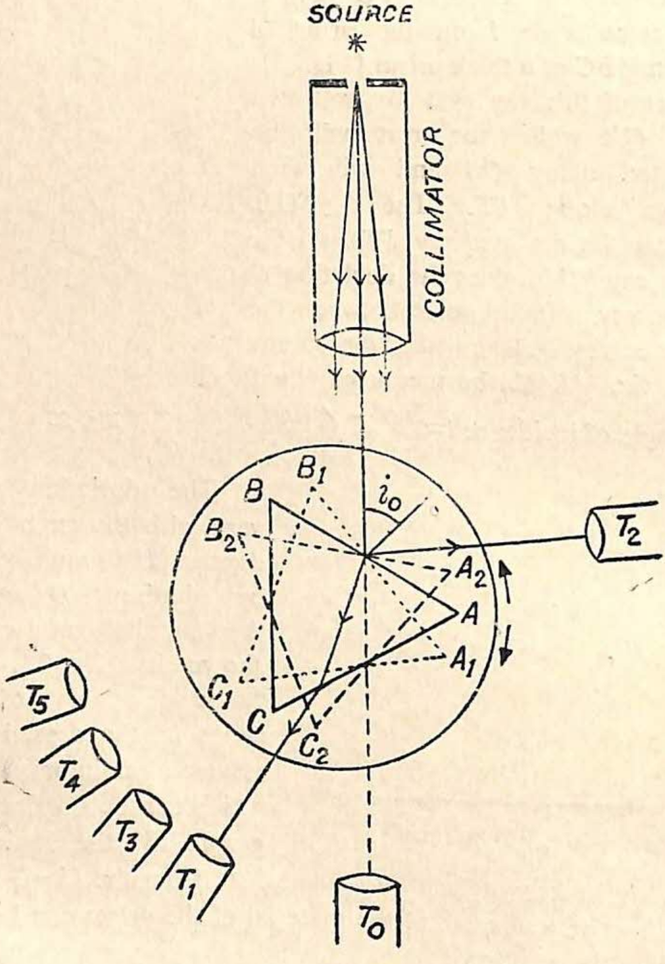

Fig. 25

respectively. In this case, *the screw should be made loose so that the prism table and hence the prism on it, can be rotated without any rotation of the scale or vernier.* The rotation of the scale or vernier can then be effected by the rotation of the telescope only.

The telescope is brought in line with the collimator (to the position T_0) and by giving a slow motion to the telescope (by the tangent screw) the centre of the cross-wire is made coincident with one edge (say right edge) of the direct image of the slit. The readings (R_0) of both the verniers are noted [Fig. 25].

(*iii*) The prism is now placed on the prism table with one of its faces (say the face AB) directed towards the collimator and the centre of the prism coinciding with that of the table (Fig. 25). By turning the prism-table, the prism is brought to an approximate position (position ABC) of minimum deviation [for details of this adjustment, see operation (*vi*) of procedure of Expt. 17 on p. 79]. The telescope is then turned (to the position T_1) to receive this approximately minimum deviated light and by its slow movement the centre of the cross-wire is made coincident with one edge (say right edge) of the refracted image. The readings (R_1) of both the verniers are noted. Thus the deviation of the ray is given by, $D=(R_1 \sim R_0)$.

(*iv*) The reflected image is first seen by the naked eye and then the telescope is taken to the position of the eye (position T_2 of Fig. 25) to receive the reflected image. The telescope is slowly shifted by the tangent screw until the centre of the cross-wire coincides with the same edge (right edge) of the reflected image. The readings (R_2) of both verniers are noted. The angle of incidence for the ray is given by, $i=\frac{180-(R_2 \sim R_0)}{2}$.

From operations (*ii*) to (*iv*) we can get the approximate value of minimum deviation (D) and its corresponding angle of incidence (i).

(*v*) The telescope is now brought back to the former position (position T_1) at which the deviation was approximately minimum. From this position (position T_1), it is now shifted to another position (position T_3) towards the base of the prism by about 2°. By this, the deviation will now be greater than the former approximate minimum deviation by about 2°. The prism is now rotated in a direction so that its edge A goes towards the telescope (the $A_1B_1C_1$ position), by which the angle of incidence will now be greater than the former value. This rotation of the prism table will be continued until one edge (say right edge) of the refracted image coincides with the centre of the cross-wire. The readings of both the verniers are noted by which the deviation (D) of this refracted ray can be found out.

(*vi*) The reflected image is first seen by the naked eye and then the telescope is taken to the position of eye to receive the reflected image. The position of the telescope is then adjusted slowly until the centre of the cross-wire coincides with the same edge of the reflected image as before. The readings of the two verniers are noted from which the angle of incidence (i) for this reflected ray can be found out.

(*vii*) The telescope is now taken back to its former position (position T_3) until the centre of the cross-wire coincides with one edge (say right edge) of the refracted image.

The prism is now taken to another position (position $A_2B_2C_2$) by rotating it in a direction in which its edge A moves towards the collimator (by which the angle of incidence will be less than that at ABC position of the prism) until the same edge of the refracted image coincides with the centre of the cross-wire.

(*viii*) The reflected image for this position of the prism (position $A_2B_2C_2$) is again received by rotating the telescope towards the collimator and its position is slowly adjusted until the centre of the cross-wire coincides with one edge (say right edge) of the reflected image. The readings of both the verniers are noted from which the angle of incidence for this position of the prism can be found out.

By performing operations (*v*) to (*viii*) we get two angles of incidence for a particular deviation which is greater than the approximate minimum deviation by about 2°.

(*ix*) The entire operations from (*v*) to (*viii*) are to be repeated by shifting the telescope towards the base of the prism (by which the deviation increases) to two more different positions (positions T_4 and T_5) which are respectively 4° and 6° away from the approximate minimum deviation position.

Thus we get six angles of incidence for three different deviations which are successively greater than the approximate minimum deviation by about 2°, 4° and 6°.

(x) If R_0, R_1 and R_2 are the readings of the vernier for direct, refracted and reflected rays respectively, then the deviation is given by, $D=(R_1 \sim R_0)$ while the angle of incidence is given by, $i=\frac{180^\circ-(R_2 \sim R_0)}{2}$

(xi) By plotting D against i, a graph is drawn from which the minimum diviation D_m is found out. If the value of A is known then μ can also be calculated by (1).

Experimental data :

(A). *Vernier constant determination :—*

Smallest circular scale division=(...)°

......vernier divisions=.....scale divisions.

$v.c$=1 s.d.−1 v.d. =...s.d.=(......).

(B). *Readings (R_0) for direct rays :*

TABLE I

[Numerical figures given in the table are for illustrations only].

Vernier number	Readings of,			
	Scale (S)	Vernier (V)	Total $=R_0$ $=(S+V.)$	Mean R_0
1st	354°30′	11′	354°41′	354°41′
	...	10′	354°40′	
	...	12′	354°42′	
2nd	174°30′	15′	174°45′	174°45′
	...	17′	174°47′	
	...	18′	174°43′	

(C). *Deviation (D)—incident angle (i) record :—*

TABLE II

[Numerical figures given in the table are for illustrations only]

No of obs.	Vernier no.	Readings of the refracted rays of,				Readings for the reflected rays of,				Deviation $= D$ [Table I $= (R_1 \sim R_0)$ gives R_0]	Incident angle $= i = \frac{180-(R_2 \sim R_0)}{2}$	Mean D	Mean i	D_m from graph
		Scale (S)	Vernier (V)	Total $= R_1 = (S+V)$	Mean R_1	Scale (S)	Vernier (V)	Total $= R_2 = (S+V)$	Mean R_2					
1	1st	306°30′	0′	...	306°30′	66°	20′	...	66°20′	48°11′	54°11′	48°9′ (nearly min.)	54°11′	
		...	1′	...		...	...	...						
		...	0′	...		...	...	...						
	2nd	126°30′	9′	...	126°39′	246°	22′	...	246°22′	48°6′	54°11′			
		...	8′	...		...	22′	...						
		...	9′	...		...	21′	...						
2	1st	304°	15′	...	304°15′	84°	8′	...	84°8′	50°26′	45°17′	50°23′	45°20′	...
		...	13′	...		...	8′	...						
		...	17′	...		...	7	...						
	2nd	124°	25′	...	124°25′	264°	4′	...	264°4′	50°20′	45°22′			
		...	25′	...		...	4′	...						
		...	24′	...		...	4′	...						
3	1st	304°30′	0′	...	304°30′	46°	7′	...	45°7′	50°11′	64°17′	50°8	64°18′	
		...	1′	...		...	8′	...						
		...	0′	...		...	6′	...						
	2nd	124°30′	11′	...	124°41′	226°	6′	...	226°7′	50°4′	64°19′			
		...	11′	...		...	8′	...						
		...	11′	...		...	8′	...						
4												52° nearly		
5												52° nearly		
6												54° nearly		
7												54° nearly		

N.B.—[For 1st. vernier $(R_2 \sim R_0) = R_2 + (360 - R_0)$]

(C). *To draw (i—D) curve* :—

To draw $(i-D)$ curve, the angle of incidence (i) is plotted along x-axis while the corresponding value of deviation is plotted along y-axis. From the sample data shown in Table III, and $(i-D)$ curve is drawn, the nature of which is shown in Fig. 26.

TABLE III

$i\rightarrow$	54°11′	46°49′	42°42′	61°18′	68°24′
$D\rightarrow$	48°19′	49°23′	51°51′	49°8′	51°39′

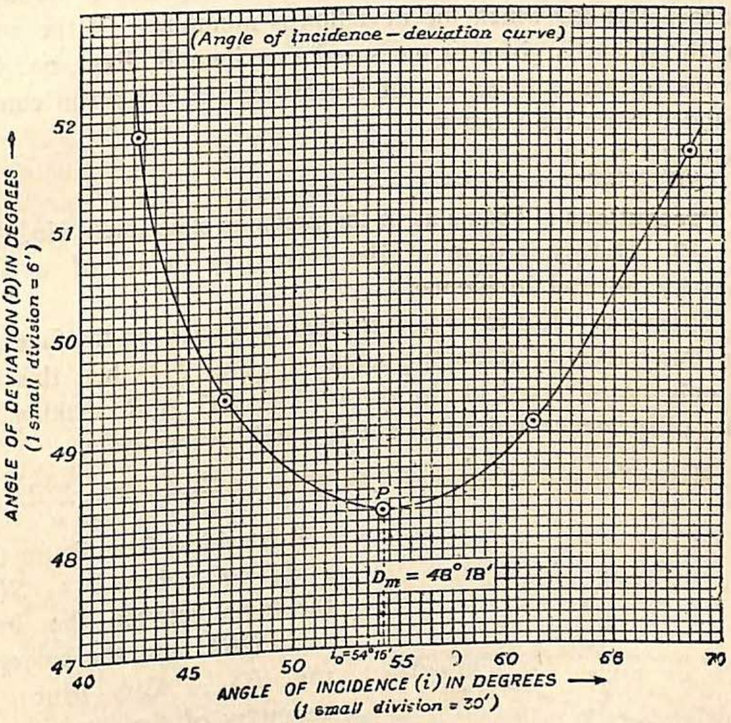

Fig 26

Round numbers smaller than the lowest values of i and D in the data are selected as the origins for i and D respectively (here 40° and 47° are selected as the origins for i and D respectively). Again the round numbers higher than the highest values of i and D in the data are taken (here 70° and 52°

are taken as the round numbers for i and D respectively, which are higher than their highest values in data).

For each quantity (i or D) the difference between its selected highest round number and the number at the origin is distributed equally amongst the number of divisions available on the axis along which that particular quantity is plotted.

After plotting the points, they are joined by a smooth curve. For a particular point P on the curve, the ordinate, *i.e.* deviation becomes minimum. The values of the ordinate and abscissa for this point P are found out from the graph which respectively give minimum deviation (D_m) and the corresponding angle of incidence (i_0) for which the deviation is minimum. If the angle A of the prism is given or measured (see item B, Expt. no. 17) then the refractive index (μ) of the material of the prism can be calculated from the relation,

$$\mu=\frac{\sin (A+D_m)/2}{\sin A/2}.$$

Precautions : [Same as in the previous experiment No. 17].

19. Determination of the refractive index of a thin prism by normal incidence.

Theory : If a ray PQ is incident normally on the face AB of a thin prism of refracting angle A [Fig. 27] then this ray will only be refracted at the second face AC at R, making the angles of incidence and refraction as r and i respectively.

Hence for refraction at R, we have, $\mu=\frac{\sin i}{\sin r}=\frac{\sin (D+r)}{\sin r}$.

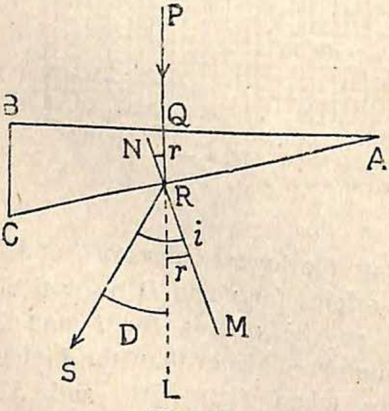

Fig. 27

It is evident from figure that $i=(D+r)$, where $D=\angle SRL$, the angle between the direct ray $PQRL$ and the emergent ray RS. Also from the geometry of the figure $r=A$.

$$\therefore \mu=\frac{\sin (D+A)}{\sin A} \qquad ...(1)$$

When A is very small, i is also small and hence, we may write,

$$\mu=\frac{D+A}{A}=1+\frac{D}{A} \qquad ...(2)$$

If the angle of the prism is small (less than 5°), the formula (2) is employed to find (μ) otherwise formula (1) will have to be employed.

Procedure : (*i*) The slit of the spectrometer is illuminated by sodium light and is levelled and focussed for parallel rays by Schuster's method. [See adjustments (*a*), (*b*), (*c*) and (*d*) of Art. 16 and p. 72-73].

(*ii*) The vernier constants of both the verniers are determined so that the position of the prism table or that of the telescope can be noted with respect to both the verniers.

(*iii*) Direct light is received by the telescope and by its slow motion, the centre of the cross-wire is made coincident with one edge (say right edge) of the image. The reading of the vernier (only first vernier will do) is noted. Let it be α. The telescope is then rotated exactly by 90°, so that the reading of the vernier (first vernier) is now either ($\alpha+90°$) or ($\alpha-90°$). This time, the axes of the collimator and the telescope are at right angles to each other.

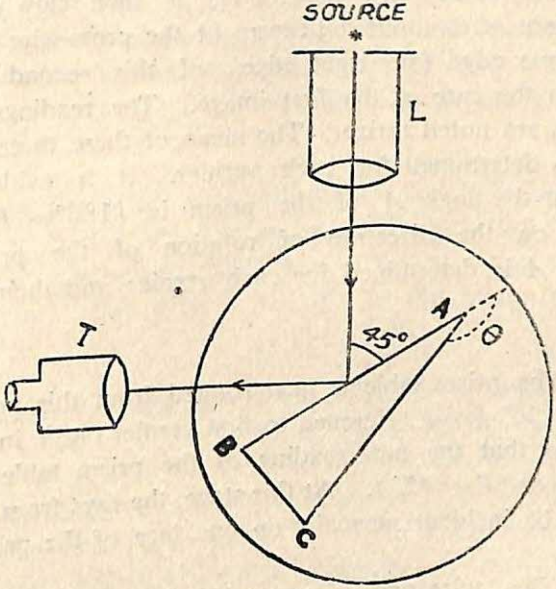

Fig. 28

(*iv*) The thin prism is then placed on the prism table so that the faces and edge of the prism are vertical and the centre of the prism coincides with the centre of the table. The prism table is then rotated until the light reflected from one face of the prism (say, the face AB) enters the telescope T [Fig. 28]. Three independent readings of both the verniers are noted when the centre of the cross-wire is made to coincide with one edge (say right edge) of this reflected image by slowly moving the prism table with the help of the tangent screw. The mean of these three readings (R_1 say) is determined for each vernier.

(*v*) The prism table is now rotated until the light reflected from the other face of the prism (say, the face AC) enters the fixed telescope at T. The prism table is then slowly rotated by the tangent screw until the centre of the cross-wire coincides with the same edge (say right edge) of this second reflected image as in the case of the first image. The readings of both the verniers are noted thrice. The mean of these three readings (R_2 say) is determined for each vernier. It is evident from Fig. 28 that the angle A of the prism is $[180° \sim (R_2 \sim R_1)]$, depending on the direction of rotation of the prism table. This angle A is determined for each vernier and their mean is taken.

(*vi*) The prism table is next rotated from this position by an angle of 45° [with reference to first vernier only] in a proper direction so that the new reading of the prism table is either $(R_2+45°)$ or $(R_2-45°)$. At this stage, the rays from the collimator will be incident normally on one face of the prism.

(*vii*) The telescope is now *shifted gradually from the thicker end of the prism* [*i.e.* from the base-side (BC) of the prism] and is brought almost in line with the collimator. If two images are seen then the first image (which lies towards the thicker end or the base-side of the prism) is the refracted or deviated image while the second image (which lies towards the thinner end or the edge-side of the prism) is the direct image. [Two images will be observed only when the height of the prism is small enough to allow some of the rays from the collimator to pass above the prism and enter the telescope.]

The telescope is *shifted gradually from the thicker end of the prism* and the centre of the cross-wire is made coincident with one edge (say right edge) of the first image (*i.e.* the image existing towards the thicker end of the prism). This image is the refracted image and the readings of both the verniers are noted thrice.

From this position the telescope is *slowly shifted towards the thinner end of the prism* to receive the second image, which is the direct image. The readings of both the verniers are noted thrice when the centre of the cross-wire coincides with one edge (say right edge) of the image. The difference between the two readings, corresponding to the first and second image, is determined for each vernier. The mean of these two differences, gives the deviation D of the ray incident normally on the first face of the prism.

If now the prism is withdrawn, the centre of the cross-wire which was already made coincident with one edge of the second image will still remain coincident with the same edge of the direct image. This proves that the second image is the direct image.

(*viii*) In the case, where the height of the prism, placed on the prism table, is sufficient to intercept all the rays from the collimator, then only the refracted image will be obtained. As before [operation (*vii*)], the readings of both the verniers, are noted thrice when this image is received by telescope. The prism is then withdrawn and the readings of both the verniers are again noted thrice when the telescope receives the direct image. The difference between the deviated and direct readings is determined for each vernier and the mean of these two differences gives the deviation D of the ray.

(*ix*) Knowing the deviation D and the angle A of the prism μ can be calculated.

Experimental data :

(A). *Vernier constant determination :—*

. . . v.d. = . . . s.d.

∴ 1 v. d. = . . . s. d.

$v.\ c. = 1$ s. d. $- 1$ v. d. $=$ . . . s. d. $=$ . . .

(B). *To find A :—*

Direct R for 1st vernier $= \measuredangle = (148°30') + (1') = 148°31'$.

Telescope kept at $= (\measuredangle \pm 90°) = (148°31 - 90°) = 58°31'$.

TABLE I

[Numerical figures given in the table are for illustrations only].

Vernier number	Readings for *first position* of prism-table of,				Readings for *second position* of prism-table of,				Difference $= \theta$	$(180 \sim \theta) = A$	Mean A
	Scale (S)	Vernier (V)	Total $= (S+V)$	Mean	Scale (S)	Vernier (V)	Total $= (S+V)$	Mean			
First	35°30′	10′	35°40′	$35°41' = R_1$	210°	23′	210°23′	$210°24' = R_2$	$R_1 \sim R_2$ = 174°43′	5° 17′	
	...	12′	...42′		...	24′	... 24′				
	...	11′	...41′		...	25′	... 25′				
Second	...	...	...	$... = R_3$	...	...	...	$... = R_4$	$R_3 \sim R_4$ = ...	...	...
	...	...	...		...	...	...				
	...	...	...		...	...	...				

(C). *To find D :—*

Prism table reading when the rays from the collimator are reflected from the face AC of the prism, and enter the telescope placed normal to the collimator rays is, $R_2 = 210°24'$.

Prism table set at $= (R_2 \pm 45°) = (210°24' + 45°) = 255°24'$.

TABLE II

[Numerical figures in the table are for illustrations only].

Vernier number	Readings for *deviated* image of,				Readings for *direct* image of,				Difference = Deviation (D)	Mean (D)
	Scale (S)	Vernier (V)	Total = (S+V)	Mean	Scale (S)	Vernier (V)	Total = (S+V)	Mean		
First	348°	7′	348°7′	348°8′ = R_1	345°30′	1′	345°31′	345°31′ = R_2	$R_1 \sim R_2$ = 2°37′	....
	...	9′	... 9′		...	0′	... 30′			
	...	8′	... 8′		...	2′	... 32′			
Second	...	...	...	... = R_3	...	...	....	... = R_4	$R_3 \sim R_4$	
	...	...	...		...	...	...		...	
	...	...	...		...	...	...			

Calculations : $\mu = 1 + \frac{D}{A} = 1 + \frac{2°37'}{5°17'} = 1 + \frac{157'}{317'} = ...$

Precautions : [Same as in Expt. No. 17]

Oral Questions for spectrometer experiments and their answers

1. Define the terms : (*a*) edge and principal section of a prism. (*b*) face, base and angle of a prism.

For the answer of (*a*), see Art. 3·12 of 'A Text Book on Light, by the author (*b*) The two surfaces of the prism which are required for incidence and emergence of a ray of light are called the refracting faces of the prism while the third face of the prism is called the base of the prism. The angle included between the two refracting faces is called the angle of the prism.

2. How does the deviation of a ray vary with its angle of incidence ?

The deviation becomes minimum at a particular angle of incidence, but it always increases when the angle of incidence is either greater or smaller than that at which the deviation becomes minimum.

3. How does the deviation change with the colour of incident light ?

Deviation is greater for violet than for red light.

4. What is the condition for obtaining minimum deviation ?

The deviation of ray would be minimum, when its angles of incidence and emergence are equal.

5. What is monochromatic light ? Do you consider the sodium light strictly monochromatic ?

Light of a particular wavelength is called monochromatic light. Sodium light is not monochromatic ; for it contains light of two wave-lengths of values 5890 Å and 5896 Å.

6. Can you expect an emergent ray, for any incident ray on the prism ?

No : for a prism of definite angle, there is a certain range of the angles of incidence within which emergent rays are possible.

7. How does the deviation of a ray vary with the change of the angle of the prism ?

Deviation increases with the increase of the angle of the prism.

8. Why do you take sodium light and not white light to find the refractive index of a prism ?

Sodium light gives a single image of the slit and a single value of minimum deviation while white light gives a spectrum and the value of minimum deviation is different for light of different colours.

9. What is the necessity of levelling the spectrometer ?

Otherwise the position of the image will be different for different positions of the telescope.

10. Why concentric circles and straight lines are marked on the prism table ?

Straight lines are required for optical levelling of the prism table so that the faces of the prism may be vertical. Circles are required to make the centre of the prism coincident with that of the prism table.

11. Why the telescope and the collimator are adjusted for parallel rays ?

When the incident rays are either divergent or convergent, the distance of the image formed by the prism will be different for different positions of the prism (for the angle of incidence will change with the change of the position of the prism), Hence the image will remain focussed for one position of the prism but will go out of focus for another position of the prism. If the incident rays are parallel, then both the object and the image of the prism will be at infinity and the telescope once focussed for the image will remain so for every position of the prism.

12. Why different procedures are adopted to measure the angles of thick and thin prisms ?

The angle θ between the rays reflected from the two faces of a prism of angle A, is $2A$. For thick prism, A is large and hence θ is also large. Thus for greater accuracy, the telescope is rotated to measure θ and A becomes equal to $\theta/2$. For thin prism, A is very small and for greater accuracy, the prism table is rotated by an angle θ to bring the rays reflected from the two faces of the prism into a fixed telescope and A becomes equal to $(180 \sim \theta)$.

13. Why do you record the readings of the two verniers ?

To avoid the error arising out of the non-coincidence of the centre of the circular scale with the axis of rotation of the telescope.

14. In measuring A of thick prism why the edge of the prism is placed at the centre of the table ?

By such placing of the prism, the error in the measurement of A would be minimum when the incident rays are not perfectly parallel.

15. To measure the minimum deviation of a ray by a thick prism, why the centres of the prism and the prism-table are kept coincident ?

In that case a full pencil of light coming from the collimator, will be incident on the prism and the image would be bright.

16. When taking the readings, why the centre of the cross-wire is made coincident with one edge of the image ?

As the images of the both the cross-wire and the slit have certain width, the centre of the cross-wire should be made coincident, with one edge of the slit image (say right edge) to have greater accuracy in the recording of scale readings.

17. What do you mean by dispersion and dispersive power ? (See Art. 8·7 of 'A Text Book on Light' by the author.)

18. What will happen when two prisms are combined ?

(*a*) Two prisms can be combined to have (*i*) dispersion but no deviation, (*ii*) deviation but no dispersion [see Art. 8.12, of 'A Text Book on Light' by the author]. (*b*) When two prisms are combined with their angles in the same direction, the resultant deviation and dispersion will be greater than those produced by a single prism. (*c*) Two identical prisms can be combined with their angles in the opposite direction to annual both dispersion and deviation. The combination behaves as a plate.

19. What kind of image is produced by the telescope ?

The telescope produces a virtual image at infinity. The objective of the telescope produces a real diminished image while the eye-piece produces a virtual magnified image.

20. What is the necessity of avoiding parallax between the images of the cross-wire and the slit ?

Otherwise coincidence of the image of the cross-wire with that of the slit will change with the movement of the eye and as a result error in the recording of the readings will be introduced.

20. Determination of the refractive index of a prism (a) by finding the minimum deviation of a ray through it from its (i—D) curve and (b) by measuring the angle of the prism, with the help of some pins.

Apparatus : Apparatus required for this purpose are,— (1) a prism, (2) a drawing board with a paper fixed on it, (3) some pins and (4) an instrument box.

Theory : The minimum deviation (D_m) of a ray through a prism and the angle (A) of the prism are related to the refractive index (μ) of the material of the prism by the relation,

$$\mu = \frac{\sin (A+D_m)/2}{\sin A/2} \quad \cdot\cdot \quad \cdots \quad \cdots \quad (1)$$

The deviation D of a ray through a prism changes with the angle of incidence i of the ray. If the deviation (D) of different rays, incident at different angles (i) on a prism, be plotted on a graph paper, with the values of i along x-axis and their corresponding values of D along y-axis then the graph would be of the nature as shown in Fig. 26. The minimum value of the ordinate obtained from this curve would be the minimum deviation D_m of the prism.

Again, if the reflected rays (E_1F_1 & M_1N_1) corresponding to two parallel incident rays (C_1D_1 & K_1L_1) on the two faces (AB & AC) of the prism be respectively drawn, then the angle $\angle F_1O_1N_1$) between these two reflected rays will be double the angle (A) of the prism [Fig. 30].

For, when the reflecting surface goes from one face (AB) of the prism to its another face (AC) by rotating by an angle A, the reflected rays must rotate by an angle $2A$. Half of this angle of rotation ($\angle F_1 O_1N_1$) of the reflected beam will give A.

Procedure for Experiment (a), i. e. to find D_m :—

(i) On the sheet of white paper, fixed on a wooden board, seven outlines of the given prism are drawn at seven different places (seven figures, instead of one figure, are drawn to avoid cumbrousness in a single figure).

(*ii*) Near the middle point Q of the line AB of each of the seven outlines (ABC) of the prism, straight line PQ is drawn making with AB an angle ranging from 25° in the first figure [shown in Fig. 29] to 55° in the seventh figure [not shown in the figure], so that the angle between PQ and AB increases by steps of 5° from one figure to the next. The angle of incidence will thus vary from 65° $(=90-25)$ in the first figure to 35° $(=90-55)$ in the seventh figure.

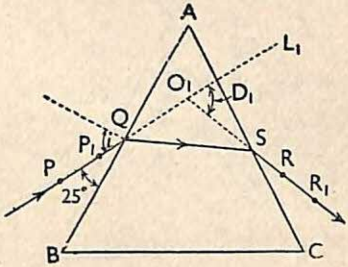

Fig. 29

(*iii*) The prism is now placed on its first outline ABC [Fig. 29] and two pins P and P_1 are fixed on the line PQ so that the pin P_1 is very close to the surface AB, while the pin P is at a distance from AB. Two other pins R **(very** close to the surface AC) and R_1 (at a distance from AC) are fixed on the side AC of the prism so that they are in one straight line with the images of the pins P and P_1. The prism is now withdrawn. The pin-prick points P, P_1 and R, R_1 on the paper are now joined and produced to cut at O_1. The angle $\angle L_1O_1R_1$ is measured by a protractor and this angle is the deviation D_1 of the ray PQ in the first figure. The angle θ, between PQ and AB (which has already been measured) when subtracted from 90° [*i.e.* $(90°-\theta)$] we get the angle of incidence i_1 of the ray PQ in the first figure.

(*iv*) The prism is now placed one after another on the second, third, etc. outline of the prism and finally on its seventh outline. In each case the operation (*iii*) is repeated. Thus we get (D_2, i_2) from second figure (D_3, i_3) from third figure and so on. Finally we get (D_7, i_7).

(*v*) A graph is now drawn with the angle of incidence (i) along x-axis, while the corresponding angle of deviation (D) along y-axis. The graph obtained would be of the type as shown in the Fig. 26. From this curve, the value of the minimum ordinate is found out which gives the minimum deviation D_m

Procedure for Experiment (b) i.e. to find A :—

(*i*) The prism is now put on another sheet of paper, fixed to the board. Three outlines of the prism like ABC [Fig. 30] are drawn on the paper at three different places.

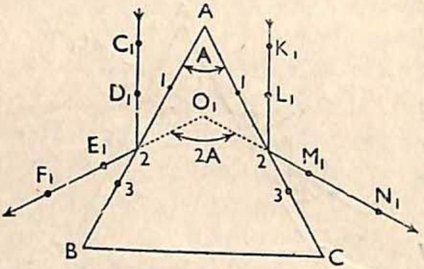

Fig. 30

(*ii*) Three pairs of parallel straight lines are drawn, so that the first pair strikes the points (1, 1) on the faces AB and AC of the first outline of the prism. The second and third pairs of parallel lines strike the points (2, 2) and (3, 3) on the two faces AB and AC of the second and third outlines of the prism respectively. [In the Fig. 30, the second pair of parallel lines C_1D_1 and K_1L_1 are shown to strike the points (2, 2) on the faces AB and CD of the second outline of the prism respectively].

(*iii*) Two pins C_1 (at a distance from AB) and D_1 (very close to AB) are fixed on the line C_1D_1 and two other pins E_1 (very close to AB) and F_1 (at a distance from AB) are fixed in such a way that the pins F_1 and E_1 appear to be in one straight line with the reflected images of C_1 and D_1 from the surface AB. The positions of the pin-pricks at C_1, D_1, E_1 and F_1 are marked and these pins are removed. When F_1 and E_1 will be joined we shall get the reflected ray corresponding to the incident ray C_1D_1 on the face AB.

(*iv*) Two pins are now fixed at K_1 (at a distance from AC) and L_1 (very close to AC) on the line K_1L_1 (which is parallel to C_1D_1) and two other pins are fixed at M_1 (very close to AC) and N_1 (at a distance from AC) until the pins M_1 and N_1 appear to be in one straight line with the reflected images of the pins K_1 and L_1 from the surface AC. The positions of the pin-pricks at K_1, L_1, M_1 and N_1 are marked and these pins are removed. When N_1 and M_1 will be joined, we shall get the reflected ray corresponding to the incident ray K_1L_1 on the face AC.

(*v*) The prism is now withdrawn and the reflected rays are drawn joining the points (F_1, E_1) and (N_1, M_1). The angle $\angle F_1 O_1 N_1$ between these two reflected rays is measured by a protractor. These gives $2A$ for the second set of observation with the parallel rays incident at points (2, 2) of the faces AB and AC of the second outline of the prism respectively.

(*vi*) The operations (*iii*) to (*v*) are repeated with two other pairs of parallel straight lines meeting the points (1, 1) and (3, 3) on the faces AB and AC of the first and third outlines of the prism respectively.

The mean of these three values of $2A$ (obtained from three outlines) when halved we get A, the angle of the prism.

Experimental data :

(A). *Records of (i—D) data* :—

TABLE I

No. of obs.	Angle in degrees between the line PQ and the surface AB. ($\theta°$)	Angle of incidence in degrees $= i =$ $(90-\theta)$	Angle of deviation in degrees (D)	Minimum deviation from graph in degrees. (D)
1	...	...	...	
2	...	...	...	
3	...	...	...	...
etc.	etc.	etc.	etc.	
7	...	...	...	

(B). *Measurement of A* :—

TABLE II

No. of obs.	For parallel rays falling on prism-outlines at points	Twice the angle of prism in degrees ($2A$)	Mean $2A$ in degrees	Mean angle of the prism in degrees (A)
1	(1. 1)	....		
2	(2. 2)	...	...	....
3	(3. 3)	...		

(C). *Drawing of* $(i-D)$ *curve* :—

[See item (*C*) in 'Experimental data' of Expt. 18.]

Calculation :

$$\mu=\frac{\sin (A+D_m)/2}{\sin A/2}= \quad \ldots \quad = \quad \ldots \quad = \quad \ldots$$

Precautions : (*i*) While tracing the reflected or refracted rays, the pins should be fixed on the paper in such a way that their feet become in one straight line with the feet of the images.

(*ii*) Angles less than half-a-degree are measured by protractor by eye-estimation only.

(*iii*) Care should be taken to draw lines on the two refracting faces strictly parallel [Fig. 30] otherwise the theory of measuring *A* will not hold good.

(*iv*) During each of the three observations in measuring *A* the prism should not be displaced from its outline.

Oral Questions and their Answers

1 to 7.—[same as the questions 1—7 at the end of Experiment 19].

8 &9.—[same as the questions 17 & 18 at the end of Experiment 19].

10. What are the factors on which the refractive index of a prism depends ?

The refractive index of a prism depends (*i*) on the material of the prism and (*ii*) on the colour of incident light. But it is independent of the angle of the prism and the angle of incidence.

11. What is the meaning of the term deviation of the ray of light through a Prism ? What factors influence the minimum deviation of a ray through the prism ?

The angle between the incident ray and the emergent ray of the prism is called 'the deviation of the ray through the prism'. The minimum deviation of a ray through the prism depends on the colour of the incident light and on the material of the prism.

21. Measurement of the width of a narrow slit by producing diffraction bands with a light of known wavelength.

Apparatus : (*i*) A spectrometer, (*ii*) an adjustable narrow slit, (*iii*) telescope with a metre scale, (*iv*) a small mirror and (*v*) a source of monochromatic light.

Theory : If a parallel beam of light of wave-length λ is incident normally on the surface of a narrow slit (AB) of width

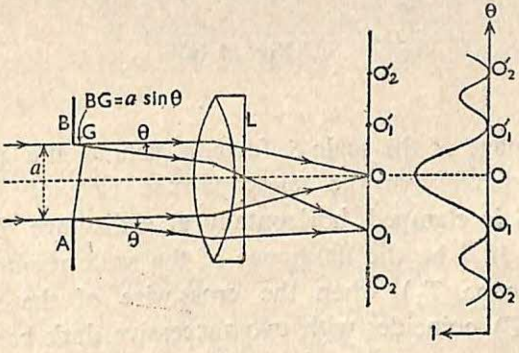

Fig. 31

a, [Fig. 31], then the angular interval (θ) between any two successive *dark bands* (either towards right or towards left of central bright band) is given by the relation,

$$a \sin\theta = \lambda$$

$$\text{or,} \quad a = \lambda/\theta \qquad \cdots \qquad \cdots \qquad (1)$$

As θ is very small, θ radian is put for $\sin\theta$. To measure such small values of θ, a telescope (T_1) and a scale (S) arrangement is employed [Fig. 31 (*a*)]. The telescope T_1 is employed to focus the image of the scale S, formed behind the plane mirror M, fixed vertically over the telescope-tube (T) of spectrometer. The scale S is clamped horizontally at a distance D from the mirror M. If d be the difference of the scale readings (as seen by the telescope T_1) when the cross-wire of the spectrometer telescope (T) coincides with two successive dark bands then the angle θ between two successive dark bands is given by, $\theta = d/2D$. Hence the relation (1) reduces to,

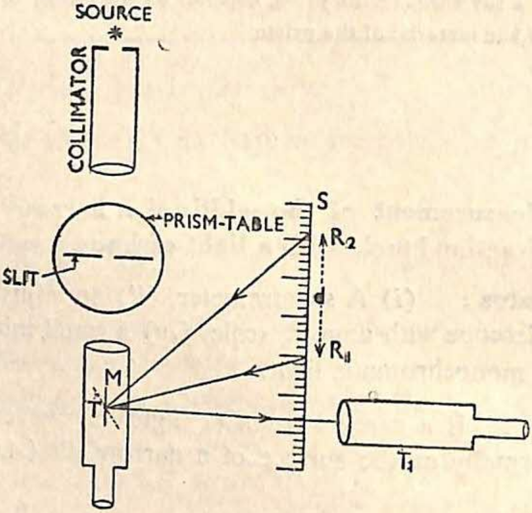

Fig. 31 (a)

$$a = 2D\lambda/d \qquad \cdots\cdots \qquad \cdots\cdots \qquad (2)$$

The relation (2) may be employed to find the breadth a of the slit.

Procedure : (*i*) The spectrometer is levelled and adjusted for parallel rays by illuminating the slit by sodium light [see adjustments (*a*), (*b*), (*c*) and (*d*) of Art. 16, *p*. 72-73]. The slit of collimator is made vertical.

(*ii*) The cross-wire of the spectrometer-telescope (T) is sharply focussed by its eye-piece. The telescope (T) is rotated to receive the direct rays from the collimator and one of its cross-wire is made parallel to the slit of collimator.

(*iii*) The frame containing the narrow slit is placed on the prism-table so that the base of the frame may remain coinciding with one of the diameters of the table and the slit may remain vertical at the centre of the table. This slit is made parallel to the cross-wire of the telescope (T) by adjusting the screw below the prism-table. The prism-table is now rotated until the parallel rays from the collimator fall on the surface of the slit normally. [This should be done by eye-estimation, for due to the roughness of the surface of the slit, it cannot be placed normal to the rays by optical method as was done in the case of a thin prism (see operations (*iii*), (*iv*) and (*vi*) of Expt. 19)]. The sodium light is now removed and the slit is illuminated by the given monochromatic light of known wave-length [usually light from an electric lamp is made to pass through a red filter and is then allowed to illuminate the collimator slit].

(*iv*) The telescope T_1 is now placed at distance (D) [D is nearly 200 cm.] from the mirror M fixed (by wax, say) vertically on the barrel of the telescope T. The scale S (illuminated by a lamp) is placed horizontally near the telescope T_1 and the positions of T_1 and also of its eye-piece are adjusted until the image of the scale S, formed behind the mirror M, is sharply seen by the telescope T_1 and there is no parallax between the scale-image and the cross-wire of T_1.

(*v*) The position of the source of light, the width of the collimator slit as well as the width of the given slit (whose breadth is to be measured) are adjusted until the diffraction dark bands are well-defined on both sides of the central bright band and equal number of dark bands are very distinct on both sides of the central bright band.

(*vi*) The point of intersection of the cross-wires of the telescope (T) is then made to coincide with the centre of the extreme left dark band (which is very distinct) and the order number of this dark band (with respect to central bright band of zero order number) as well as the reading (R') of the mark of the scale (S) which coincides with the centre of the cross-wire of the observing telescope (T_1) are noted. The telescope (T) is then shifted to make the point of intersection of its cross-wire to coincide with the next lower order number dark band and again the order number of this dark band and reading of the scale (S) as seen through the observing telescope (T_1) are noted. This process is repeated from one dark band to the next dark band towards right until the extreme right dark band (of the same highest order as that at the extreme left at start) is reached.

(*vii*) The above process of noting the order number of dark bands and the corresponding readings (R'') of the scale S [as observed through the telescope (T_1)] is repeated by starting from extreme right and ending in the extreme left.

(*viii*) The mean (R) of the two readings [*i.e.* $R=(R'+R'')/2$] for each dark band (one reading is obtained when proceeding from left towards right while another reading is obtained when proceeding from right towards left) is found out. The difference of the mean scale readings between 5 (or 6) dark bands (x) is found out from which the defference of scale readings for any two consecutive dark bands [*i.e.* $d=x/5$ (or $x/6$)] is found out.

(*ix*) The distance D between the mirror (M) and the scale (S) is measured thrice by a scale and its mean value is found out. Knowing the values of λ, d and D, the width a of the slit can be obtained from the relation (2).

Experimental data :

Wave-length of the given light$=\lambda = \cdots \times 10^{-8}$ cm.

Distance between the scale S and the mirror M is,

$$D=\frac{\cdots+\cdots+\cdots}{3}=\cdots\text{cm.}$$

Serial number of the dark fringes from left	Order No. of the dark fringes with respect to central bright band of zero order.	Readings of the scale (S) in cm. as observed through the telescope (T_1)			Diff. of scale readings (R) between 5 (or 6) dark bands in cm. (x)	Mean x in cm.	Value of d is $d=x/5$ (or $x/6$) in cm.	Slit width $a=2D\lambda/d$ in cm.
		from left to right R'	from right to left R''	Mean $=R=\frac{R'+R''}{2}$				
1	4	....	...	$\ldots=R_1$	$R_6 \sim R_1=\ldots$			
2	3	...	....	$\ldots=R_2$				
3	2	...	....	$\ldots=R_3$				
4	1	...	...	$\ldots=R_4$	$R_7 \sim R_2=\ldots$			
5	0 (central bright band)	—	—	—		...	...	...
6	1	....	....	$\ldots=R_6$	$R_8 \sim R_3=\ldots$			
7	2	...	....	$\ldots=R_7$				
8	3	...	...	$\ldots=R_8$	$R_9-R_4=\ldots$			
9	4	....	....	$\ldots=R_9$				

Calculations :

$$a=\frac{2D\lambda}{d} \quad = \quad \cdots \quad = \quad \cdots \text{ cm.}$$

Precautions : (*i*) Dark bands will be clearly seen when the intensity of light illuminating the collimator-slit is greater and the position of the source is properly adjusted. For this purpose an electric lamp with a red filter may be employed or the light from the sodium flame should be concentrated by a convex lens on the collimator-slit.

(*ii*) If one surface of the plate containing narrow slit is highly polished, then the rays should be made normal to the slit by optical method otherwise by eye-estimation only.

(*iii*) Angle between the successive diffraction *dark bands* only should be measured, otherwise the formula employed will not hold good.

(*iv*) The collimator-slit, the given narrow slit and the vertical cross-wire of the spectrometer-telescope should all be made vertical and in one straight line.

(*v*) The distance between the scale (S) and the mirror (M) should be kept large, otherwise $\sin\theta$ cannot be taken as θ.

(*vi*) The light from red filter is not strictly monochromatic. Its wave-length λ lies within the range of 6000 Å to 6500 Å. Hence for calculation of a, λ may be taken as 6300° Å. The accurate method of finding a is to find first the value of λ by measuring a by microscope and then to find other values of a with that known value of λ.

Oral Questions and their Answers

1. What do you mean by diffraction of light ? How does it differ from interference ? Is the phenomenon of diffraction consistent with the principle of rectilinear propagation of light ?

The phenomenon of the bending of light waves round the sharp edge of an opaque obstacle is known as diffraction of light. Diffraction is a special kind of interference in which the secondary waves coming from the same wave front interfere and produce alternately bright and dark bands, while interference is a phenomenon in which two primary waves from two coherent sources superpose and produce alternately bright and dark bands. The phenomenon of diffraction is not consistent with the principle of rectilinear propagation of light.

2. What is the effect of widening the slit ?

The angle of diffraction for a given order of dark band depends on the width of the slit. Hence if the width of the slit be increased more and more, the angle of diffraction will decrease and ultimately the bands disappear, but we get diffraction at the two edges of the rectangular aperture.

3. What is the distinction between the Fresnel and Fraunhofer classes of diffraction ?

In Fresnel diffraction phenomena, the source and the point of observation are very close to the diffraction obstacle, while in Fraunhofer diffraction phenomena, both the source and the point of observation are at infinite distance from the diffraction obstacle.

4. What happens when the incident light is white instead of monochromatic ?

The fringes will be coloured.

5. Why do you not employ the bright bands for the measurement of the width of the slit ?

For the secondary maxima will be at those points for which the path difference for extreme rays is *nearly but not strictly* equal to odd multiples of $\lambda/2$.

21A. Determination of the radius of curvature of the lower surface of a plano-convex lens by using Newton's ring apparatus.

Apparatus : Newton's ring apparatus consists of a plano-convex lens *L* whose convex surface (having large radius of curvature) is placed in contact with a plane glass plate *G* [Fig. 32]. This lens-plate combination is enclosed in a cylindrical case provided with three levelling screws. The inside of the case is painted black while the top of the case is open and is provided with a screw cap by which suitable pressure can be uniformly applied on the rim of the lens.

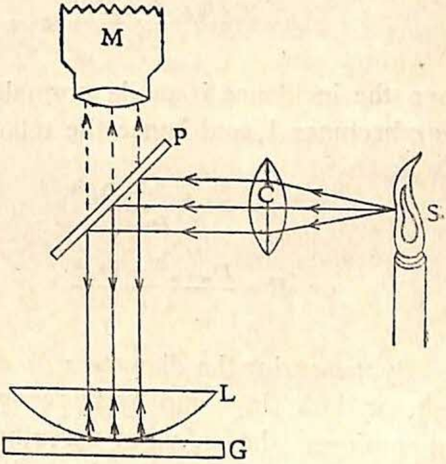

Fig. 32

A plane-parallel glass plate *P* is kept above the top of the case by making an angle of 45° with the vertical. Light from a monochromatic source *S* is made parallel by a convex lens *C* and is made to fall on the glass plate *P* at an angle of 45°. These rays will be reflected downwards and will fall normally on the air film, enclosed between the glass plate *G* and the convex surface of the plano-convex lens *L*. Newton's rings can be viewed by a low power microscope *M* from above.

Theory : When a parallel beam of monochromatic light of wave-length λ is made incident on the wedge-shaped film of air enclosed between a glass plate G and the convex surface of a plano-convex lens L of long focal length, each incident ray on the air-film will give rise to two reflected rays by reflection from the front and back surfaces of the air-film [Fig. 32(a)]. These two reflected rays will interfere (for they are coherent) and will produce alternate bright and dark concentric rings, having darkness at the common centre.

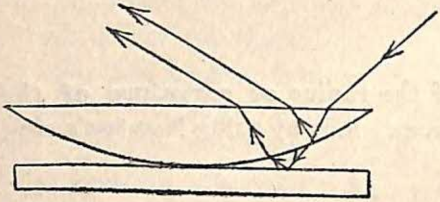

Fig. 32 (a)

If D_n and D_{n+s} be the diameters of nth and $(n+s)$th bright or dark rings and r is the angle of refraction of the ray at first surface of the air-film then the wave-length λ of the incident monochromatic light is given by,

$$\lambda=\frac{{D_{n+s}}^2-{D_n}^2}{4Rs}\cos r \qquad \cdots \qquad \cdots \quad (1)$$

when the incidence is made normal to the film, the value of $\cos r$ becomes 1, and hence the relation (1) reduces to,

$$\lambda=\frac{{D_{n+s}}^2-{D_n}^2}{Rs} \qquad \cdots \qquad \cdots \quad (2)$$

$$\text{or, } R=\frac{{D_{n+s}}^2-{D_n}^2}{4\lambda s} \qquad \cdots \qquad \cdots \quad (3)$$

By measuring the diameters D_n and D_{n+s} of nth and $(n+s)$th bright or dark rings and by knowing the wave-length λ of the light employed, the radius of curvature R of the convex surface of plano-convex lens, can be determined by using the relation (3).

Procedure : (i) The base of the microscope is made horizontal by placing a spirit level on the base and adjusting the levelling screws attached to the base. The axis of the microscope tube is made vertical and its cross-wire is sharply focussed by moving the focussing lens in or out. The vernier constant of the horizontal scale is determined.

(*ii*) Taking away the glass plate G and lens L from the case the upper surface of G and lower convex surface of L are cleaned by a cotton pad, moistened with alcohol. The centre of the upper face of G is anyhow marked and inserted within the case. The microscope is then placed above the plate P in such a way that this mark on G remains on the vertical axis of the microscope tube. By raising or lowering the microscope tube the mark on G is focussed.

(*iii*) The lens L is now placed on the glass plate so that its convex surface may remain in contact with the marked point on G. By applying the screw cap at the mouth of the case a suitable pressure is applied. The sodium flame (*i.e.* a flame produced by introducing an asbestos ring, soaked with common salt solution, in the non-luminous part of the Bunsen flame) is placed at the focus of the convex lens C. The parallel rays from the lens C, after being reflected from the plate P, are made incident on the air-film (enclosed between L and G) normally. This time, on looking through the microscope, alternate bright and dark rings will be seen. The microscope tube is then slowly adjusted until the rings are focussed as distinctly as possible.

(*iv*) The glass plate P is then adjusted, by rotating it about a horizontal axis until a large number of uniformly illuminated rings are seen. Then the position of the flame S with respect to the lens C is adjusted until a large number of rings are visible through the microscope.

(*v*) The case containing the prism-lens combination is slightly adjusted until the point of intersection of the cross-wire coincides with the centre of the central dark ring and one of the cross-wires becomes perpendicular to the line of movement of the microscope and also tangential to the bright or dark rings.

(*vi*) Counting from the first clear ring, which may be called as pth ring (as the first few rings are indistinct, it is difficult to know the order number of the first clear ring), the microscope is shifted towards the left until one of its cross-wires becomes tangential to the remotest distinctly observed bright or dark ring. The ring number (counted from the first clear ring which was called as the pth ring) of this ring is noted, as well as the position of the microscope is noted from the horizontal scale and vernier. The microscope is then displaced towards right and the same line of the cross-wires is made tangential to the next lower numbered ring. The readings of the horinzontal scale and vernier are again noted. This process of recording the ring number and the vernier readings of the horizontal scale is continued from one ring to the next, until we arrive through the centre to the extreme distinctly observed ring on the right whose order number is the same as was first noted on the extreme left. When tabulating the positions of the microscope, the two readings for the opposite ends of each ring are entered opposite to one another in a single row.

(*vii*) Another set of observations may be taken, by starting from the extreme right-end and ending in the extreme left-end of the same remotest distinctly observed ring as was employed in the former set. The difference of the two microscope readings corresponding to the two ends (one in the left and another in the right) of each ring will give the diameter of that ring. Thus from two sets of observations (one starting from left and another starting from right), we get two values of the diameter of each ring. The mean of these two values will give the diameter of the ring.

Experimental data :

(A). *Vernier constant of the microscope employed:—*

Smallest division of the main scale = . . .mm.

Total number of vernier divisions (v.d.) = . . .

$\therefore$ . . . v.d. = . . .s.d.

$\therefore$ 1 v.d= . . .s.d.

v.c. = (1 s.d. − 1 v.d.) = . . . s.d. = . . . mm. = . . . cm.

(B). *Determination of the diameters (D) of rings :—*

TABLE I

[Specific values of *s* are given for illustration only]

Ring number	Obs. started from.	Readings of microscope in cm for the, (a) left end of the ring: Scale (S)	Vernier (V) $=(v.r.)\times(v.c.)$	Total reading $R_1=(S+V)$	(b) right end of the ring: Scale (S)	Vernier (V) $=(v.r.)\times(v.c.)$	Total reading $R_2=(S+V)$	Diameter $D=(R_1 \sim R_2)$ in cm.	Mean D in cm.
p+19	left (l)	↓l … ..	…	…	… ↑l	….	…	…	…
	right (r)	.. … r↑	…	…	r↓…	…	…	…	
p+18	(l)	…	…	…	…	…	…	….	…
	(r)	…	….	…	…	….	….	…	
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.
p+1	(l)	…	…	…	….	…	…	…	…
	(r)	…	…	….	--	…	…	…	
p	(l)	↓l … ..	….	…	… ↑l	…	…	…	…
	(r)	.. … r↑	…	…	r↓…	…	…	…	

N.B. [In the first set when obs. started from left. readings (*a*) were taken first and then the readings (*b*), while in the second set, when Obs. started from right, readings, (*b*) were taken first and then the readings. (*a*)]

(C). *Determination of R from the data of Table I* :—

TABLE II

[Wave-length of given light$=\lambda=\cdots\times10^{-8}$ cm.

Ring number	Mean diameter in cm. (D)	D^2 [cm.^{2}]		Value of $(n+s)$	Value of n	Value of s	$(D_{n+s}{}^2-D_n{}^2)$ [for 10 rings]	Mean $(D_{n+s}{}^2-D_n{}^2)$	$R=\dfrac{D_{n+s}{}^2-D_n{}^2}{4\lambda s}$ in cm.
p+19	…	.. (a)	$(D_{n+s}{}^2)$	p+19	p+9	10	…(a) −(b)	…	…
p+18	….	… (a_1)		p+18	p+8	10	.. $(a_1)-(b_1)$		
etc.	etc.	etc.		etc.	etc.	etc.	etc.		
p+11	…	…. (a_8)		p+11	p+1	10	…(a_8-b_8)		
p+10	…	…. (a_9)		p+10	p.	10	…(a_9-b_9)		
p+9	…	… (b)	$(D_n{}^2)$						
p+8	…	… (b_1)							
etc.	etc.	etc.							
p+1	…	…. (b_8)							
p.	…	… (b_9)							

(D). *Determination of R from graph :—*

If a curve be drawn with the square of the diameter (D^2) of a ring as ordinate and the corresponding ring number as abscissa then the graph would be straight line as shown in the Fig. 32(b). Two points P_1 and P_2 are taken on this graph as far apart as possible. The ordinate of P_2 is $P_2N_2 = D_{n+s}^2$ (say) while the ordinate of P_1 is $P_1N_1 = D_n^2$ (say). $N_1N_2 = s$ =difference of ring numbers. Hence the slope of this straight line is $m = \dfrac{P_2N_2 - P_1N_1}{N_1N_2}$

or, $m = \dfrac{D_{n+s}^2 - D_n^2}{s}$.

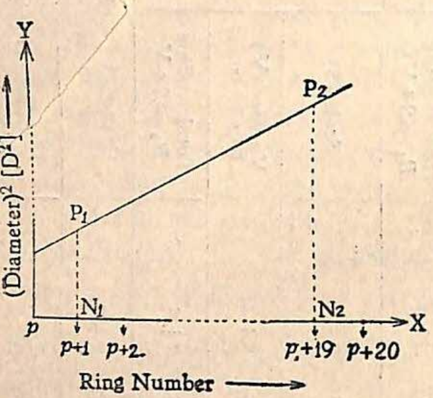

Fig. 32(*b*)

Finding P_2N_2, P_1N_1 and N_1N_2 from the graph, the value of the radius of curvature is given by, $R = m/4\lambda$.

Discussions : (*i*) As the first few rings are indistinct, it is very difficult to ascertain the exact ring number of the first clearest ring.

(*ii*) In this arrangement, the rings (which are formed in the air-film lying in the space between the lens and the glass plate are seen after refraction through the lens and the error due to this is very small if the lens employed is thin.

(*iii*) When the rings are visible, in the microscope, it may sometimes be necessary to shift the lens to-and-fro and across to get bright and clear bands.

Oral Questions and their Answers

1. What do you mean by the term interference of light ?—When waves from two sources, which are derived from the same source, proceed

in the same direction, they on superposition produce alternately bright and dark bands. This phenomenon is known as interference of light.

2. Under what condition interference would occur ?—The essential condition for interference is that the two interfering waves must have a constant phase relationship between them for all times and this can be obtained only when the two sources (which are sending waves) are coherent.

3. How interference occurs in Newton's ring ?—Here the two waves derived by reflection from the front and back surfaces of the air film are derived from the same wave-front and hence coherent. Thus the two reflected waves will produce interference.

4. Is the central ring bright or dark ? Explain.

The central ring with reflected light is dark due to the change of phase of π by reflection from the denser medium, *viz.*, glass plate.

5. What happens when white light is employed ?—The rings become coloured and a small number of rings are seen.

6. What happens when an illuminated slit is employed instead of an extended source ?—Only a portion of the rings will be seen.

7. Where the rings are formed ?—The rings are formed in the air film enclosed between the lens L and the glass plate G.

8. Is it possible to see the central ring bright ?—Yes ; when the rings are seen with transmitted light, the central ring would be bright.

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CHAPTER II

ELECTRICITY

22. Some electrical accessories and their uses.

(a) Keys.

Keys are devices by which electrical currents can be sent or stopped in a circuit at will. The different types of keys which are commonly employed in the laboratory are shown below.

(i) Plug key : The plan of arrangement of the key is shown in Fig. 33 (*a*). It is evident from the figure that when the plug *P* is inserted in the gap *O* between the two metal blocks *A* and *B*, the current can flow in the circuit. When the plug *P* is taken out, the current at once ceases to flow due to the introduction of infinite resistance in the air gap *O*.

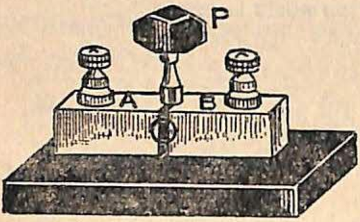

Fig. 33(*a*)

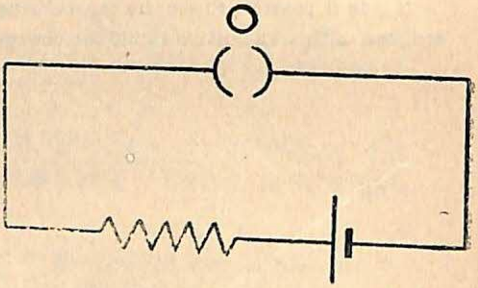

Fig. 33(*b*)

Fig. 33 (*b*) gives a diagrammatic connection of the key in a circuit containing a battery and a resistance. The gap at *O* in this figure represents the air gap *O* in the plug key indicated in Fig. 33 (*a*).

(ii) Two-way key : The actual plan of arrangement of

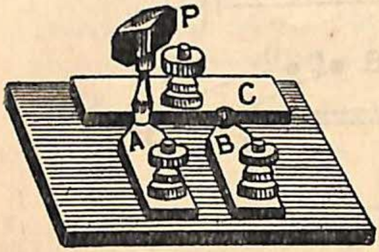

Fig. 33(*c*)

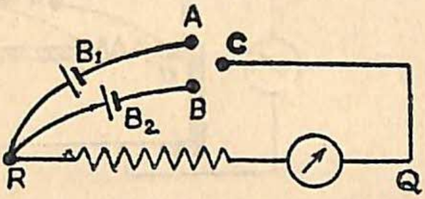

Fig 33(*d*)

the key is shown in Fig. 33(*c*) while the method of its use in a circuit is shown in Fig. 33(*d*). When the plug *P* is put in the gap between *A* and *C* [Fig. 33(*c*)], the circuit *RQ* will be joined with the battery B_1 [Fig. 33(*d*)]. On the other hand, if the plug *P* is put in the gap between *B* and *C* [Fig. 33(*c*)], then the battery B_2 will only be joined with the circuit *RQ* [Fig. 33(*d*)]. Binding screws are fixed to the metal blocks *A, B* and *C*.

(iii) Four-way key : Actual body of the key is of the type

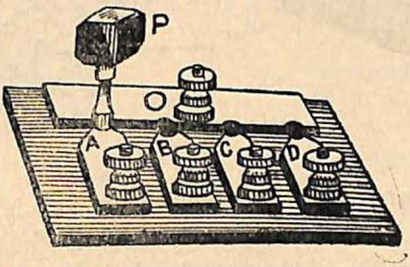

Fig. 34(*a*)

as shown in Fig. 34(*a*) above, while its application in a circuit is shown in Fig. 34(*b*) below.

If the plug *P* of the key is alternately inserted in the gaps between *A* and *O*, *B* and *O*, *C* and *O*, and *D* and *O*, then it is evident from Fig. 34(*b*) that the points *a*, *b*, *c* and *d* of a circuit will be joined to the galvanometer one after another.

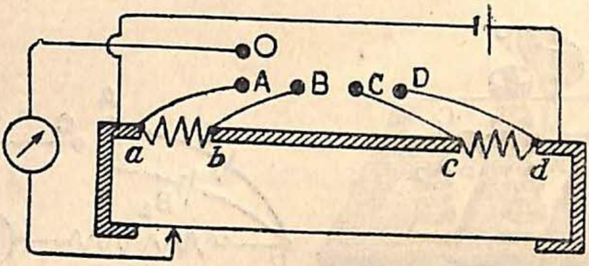

Fig 34(*b*)

(iv) Tapping key :— Tapping key is a device by which the circuit can be kept closed so long as the key is kept pressed by hand. As soon as the hand is removed, the circuit becomes open. It is suitable where the circuit is to be closed momentarily. Fig. 35(*a*) is the actual plan whereas Fig. 35(*b*) is the diagrammatic plan of the tapping key. If the button *B* of the key is pressed, then the circuit will be closed, but on releasing the button *B*, the circuit will be open.

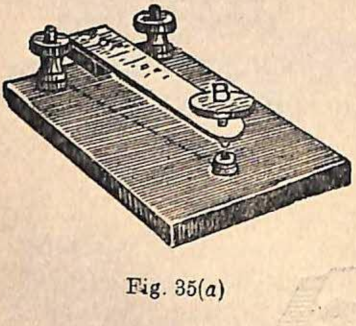

Fig. 35(*a*)

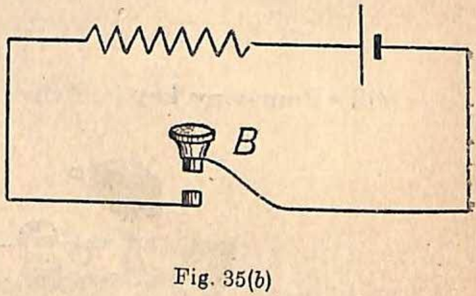

Fig. 35(*b*)

(b) Commutators.

Commutator is an arrangement by which the direction of electric current in a circuit can be reversed. Different types of commutators which are employed in the laboratory are shown below.

(i) Plug commutator : In this commutator there are four blocks of metal with four binding screws *A*, *B*, *C* and *D* on them. They are fixed on an ebonite plate in such way that four gaps are created, having one gap between two adjacent blocks.

The method of using the commutator is shown in Fig. 36(*b*) while its actual plan is shown in Fig. 36(*a*). *The battery and other parts of the circuit in which current is not to be reversed are to be joined to one diagonal binding screws (say B and D), while the galvanometer (G) and other parts in which the current is to be reversed are to be connected across another diagonal (say A and C). It is evident from Fig.* 36(*b*) *that if the two plugs are inserted* between *AB* and *CD*, then a current will flow in the galv. (*G*) along *CRGA*, on the other hand, by putting the two plugs between *AD* and *BC* the current can be sent along *AGRC*. Thus the reversing of current occurs in the galvanometer *G*.

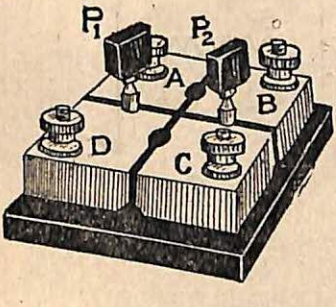

Fig. 36(*a*)

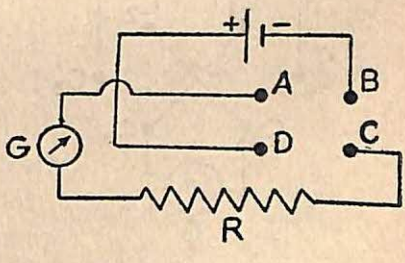

Fig. 36(*b*)

(ii) Phol's commutator : The plan of arrangement of this

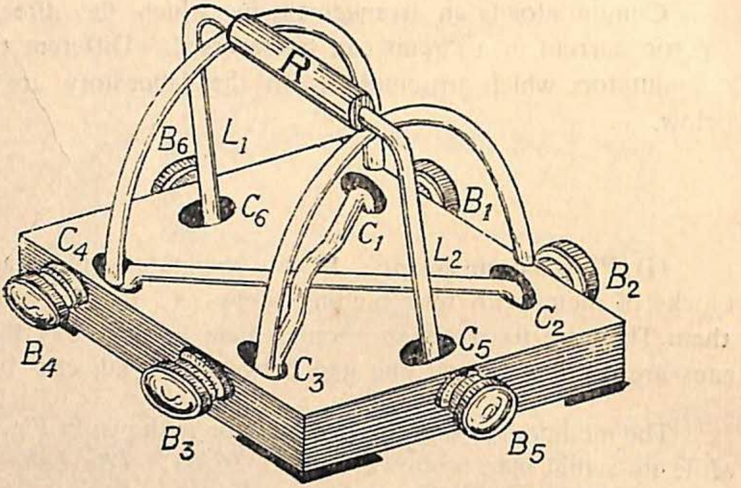

Fig. 37(*a*)

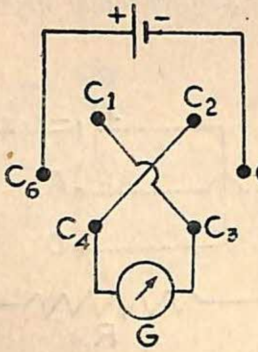

Fig. 37(*b*)

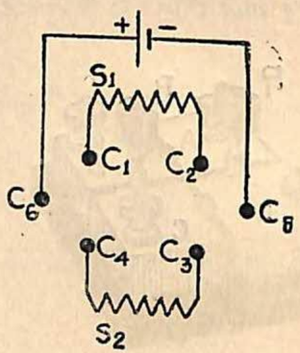

Fig. 37(*c*)

commutator is shown in Fig. 37(*a*). It consists of six mercury cups C_1, C_2, C_3, C_4, C_5 and C_6 on an ebonite base and these cups are in connection with binding screws B_1, B_2, B_3, B_4, B_5 and B_6 respectively. Two diagonally opposite cups, *viz.*, C_1, C_3 and C_2, C_4 are joined by two thick wires in such a way that one ($C_1 C_3$) is bent a little when passing over the other, to avoid any electrical contact between them. A rocker R, with an ebonite handle and six metal legs are placed in such a way that its two central legs L_1 and L_2 [Fig. 37(a)] dip in the two middle cups, C_6 and C_5 respectively. The side legs are slightly shorter than the central legs and as a result when the two front legs are put in contact with the two front mercury cups, the two back legs go out of contact with the two back mercury cups and *vice versa.*

The plan of connection is shown in the Fig. 37(b). When the rocker joins C_6C_1 and C_5C_2; the current flows in the direction $\underrightarrow{C_6C_1C_3GC_4C_2C_5}$, but when the rocker joins C_6C_4 and C_5C_3, the current flows in the direction $\underrightarrow{C_6C_4GC_3C_5}$.

Thus the direction of the current in the galvanometer is reversed.

Hence the battery and other parts in which the current is not to be reversed are to be joined between C_5C_6 while the galvanometer and other parts in which the current is to be reversed are to be connected either between C_3C_4 or between C_1C_2.

By removing the cross-connections, the commutator may be used to join different circuits S_1 and S_2 alternately to the battery circuit, as is shown in Fig. 37(c).

(c) Variable resistances.

(i) Sliding rheostat : Sliding rheostat is shown in Fig. 38(a).

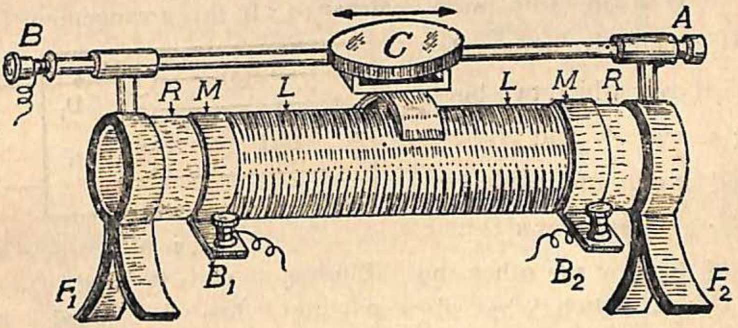

Fig. 38(a)

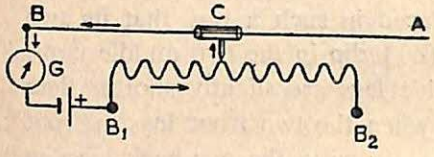

Fig. 38(b)

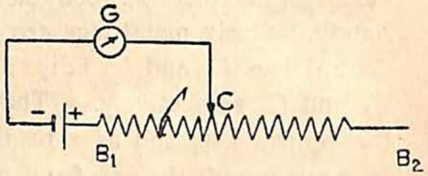

Fig. 38(c)

It consists of a coil L of bare manganin or eureka wire wound in a narrow spiral groove made on a porcelain cylinder R fitted horizontally on two frames F_1, F_2, at the two ends [Fig. 38(a)]. The ends of the coil L are joined to the two binding screws B_1 and B_2 fitted to the two metal rings M on the porcelain cylinder. A metal rod AB is fixed over the frames F_1 and F_2 and kept insulated from it. A sliding contact C can slide along AB and can touch different parts of the wire. There is a third binding screw B at one end B of AB.

The diagrammatic connections are shown in Fig. 38(b) and in Fig. 38(c), where one terminal of a battery is connected to B_1 while its another terminal is connected to B through a galvanometer. When the sliding contact C is moved towards the binding screw B_1, the resistance inserted becomes less owing to a smaller length of the wire included in the circuit. The reverse will occur when the sliding contact C is moved towards the binding screw B_2.

(ii) Adjustable lamp resistance : In this arrangement [Fig. 39], there is a wooden board over which two binding screws A and A_1 are fixed at one end, while two other binding screws D and D_1 are fixed at the other end. Binding screws A_1 and D_1 are joined to a switch S by wires passing below the board. This switch is placed in the live wire of the main. Several lamp sockets S_1, S_2, S_3, etc. are also fixed on the board. These sockets

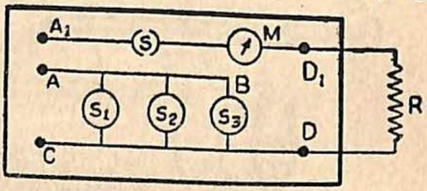

Fig. 39

are joined in parallel to the two rods *AB* and *CD* by wires going below the board. When lamps are put in the sockets, a current will flow through the filaments which will offer some resistance. This resistance will be reduced more and more as the number of lamps, joined in parallel, becomes greater and greater. The circuit *R* is joined to the binding screws *D* and D_1 while the main is joined to *A* and A_1. By making the switch on, the current will flow in the circuit the value of which can be noted from the ammeter *M* placed in series with the circuit. This type of lamp resistance is employed in battery charging and is shown in Fig. 39.

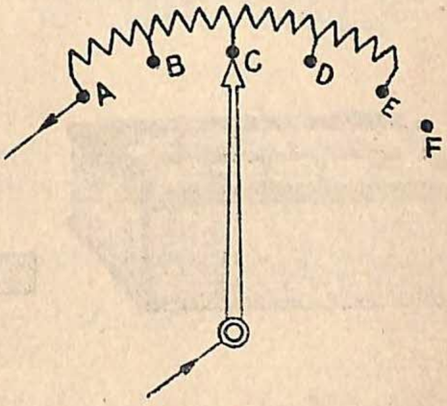

Fig. 40

(iii) Regulators or rotary rheostat : It is also a variable resistance shown in Fig. 40. Here, the current enters at the base of the rotating arm and after traversing the resistance *CA*, it then goes to the given circuit. When the rotating arm is in contact with the point *A*, the resistance inserted in the circuit is zero, but when it is in contact with *E*, full resistance is inserted in the circuit. When the arm is in contact with *F*, the circuit is made off.

(d) Resistance boxes.

An actual view of a resistance box is shown in Fig. 41 (*a*). Inside the box there are a number of *double wound* resistance coils (double winding avoids the effect of self-induction), the two terminals of each, being soldered to two metal pieces fixed at the top of the box, leaving a conical air gap between them [Fig. 41(*b*)]. The value of the resistance of a coil is marked by the side of the gap. When a plug P_2 is inserted in the gap, the resistance coil C_2 is short-circuited and hence it is cut off from the circuit. If the plug P_1 is taken out, then the current will be forced to travel through the coil C_1 whose resistance will then be inserted in the circuit. When both the plugs P_1 and P_2 are taken out, the current flows through C_1 and C_2 in series. Thus by removing a number of plugs, a number of resistance coils can be introduced in series in the circuit. *When a gap is to be closed by a plug it should be closed tight by turning the plug,* otherwise a part of the current will flow through the coil and an extra resistance will be inserted in the circuit for which we take no account. The boxes are made of various ranges containing multiples and submultiples of one ohm.

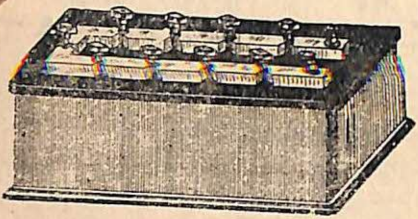

Fig. 41(*a*)

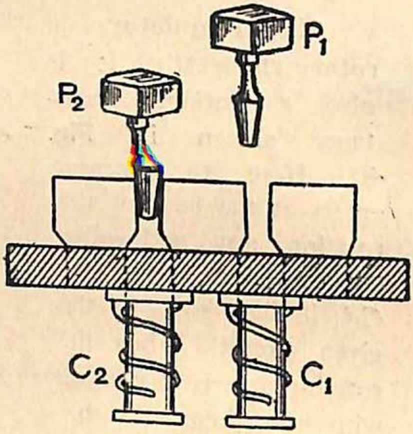

Fig. 41(*b*)

The resistance coils which are all joined in series may be arranged in several parallel rows or in the arc of a circle. When the resistance coils are arranged in the arc of a circle, the resistance box is known as *dial pattern resistance box*. In this case, any resistance can be inserted in the circuit by rotating an arm and putting it in contact with any stud kept on the box. The resistance coils between any two neighbouring studs are joined in series.

(e) Standard low resistance.

In this arrangement [Fig. 42], the ends of a very low resistance are connected to the two binding screws C, C known as *current leads* through which a current will enter and leave the resistance. Two definite points A and B of the low resistance are connected to two other binding screws P, P known as *potential leads.* The value of the resistance marked by the slide of the wire, is *for that portion of the wire that exists between A and B and not between C and C.*

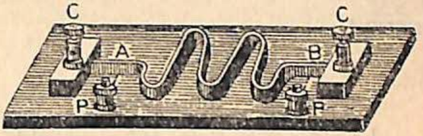

Fig. 42

23. Electrical cells and their uses.

Different types of cell which are employed in the laboratory are described below :

(a) Primary cells.

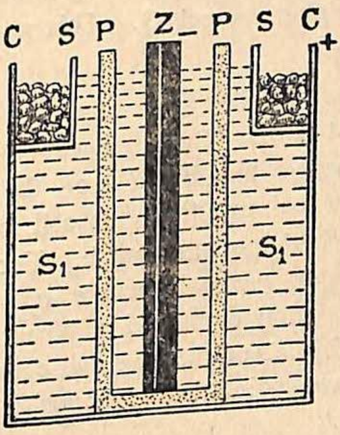

Fig. 43

(i) Daniell cell : In Fig. 43, C is a cylindrical copper vessel which serves as the *positive plate* of the cell. S_1 is the concentrated solution of copper sulphate which serves as the *depolariser* and this solution is kept saturated by allowing it to come in contact with copper sulphate crystals placed on a perforated shelf S.

Z is an amalgamated zinc rod which is the *negative plate* of the cell and this is partly immersed in the dilute sulphuric acid contained in the porous pot P. This dilute sulphuric acid serves as the *exciting liquid.*

The *E. M. F.* of the cell is 1·08 volts and *it remains steady* even when the current is drawn from the cell. Due to its *high internal resistance*, it cannot be employed for purposes where a large current is necessary. It is useful for *small but constant current.*

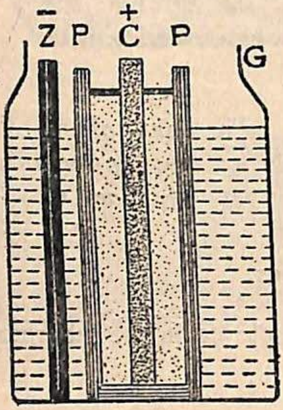

Fig. 44

(ii) Leclanche's cell : In Fig. 44, C is a carbon plate which is kept inside a porous pot P packed with a mixture of manganese dioxide and charcoal. This mixture serves as the *depolariser*. The mouth of the porous pot is covered by pitch. The *carbon plate serves as the positive plate of the cell.*

Z is an amalgamated zinc rod which serves as the *negative plate* and this is kept partly immersed in the saturated solution of ammonium chloride kept in the glass vessel G. This solution serves as the *exciting liquid.*

The *E.M.F.* of this cell is 1·4 volts. The depolariser MnO_2 is a slow oxidising agent and hence the *E.M.F.* of the cell gradually decreases as the current is drawn from the cell, owing to the partial polarisation of the high potential plate. For this reason, the *cell cannot be used for purposes where a steady current is required.* But it can be safely employed in Wheatstone bridge work, for the change of *E.M.F.* of the cell will cause an equal change of potentials of two points in the opposite arms causing no change in the null point.

(b) Secondary cells.

(i) Lead accumulator : In this cell, both the positive and negative plates are made of lead having the structure of a grid or net work [Fig. 45]. The inter-spaces in the grid are filled with a paste of red lead (Pb_3O_4) and sulphuric acid. The plates are placed in dil. H_2SO_4 of sp. gr. 1·2. Before charging, a chemical action takes place forming PbO_2 and $PbSO_4$ in both the plates.

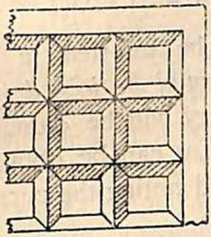

Fig. 45

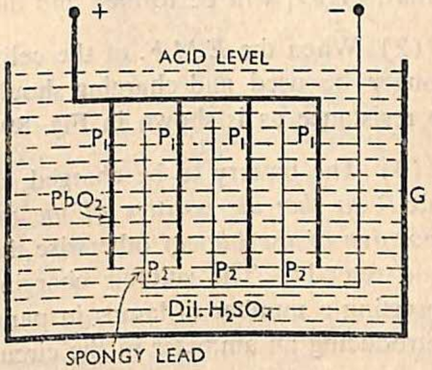

Fig. 45(a)

$$Pb_3O_4 + 2H_2SO_4 = PbO_2 + 2PbSO_4 + 2H_2O.$$

After charging, $PbSO_4$ of the positive plate is converted to PbO_2 while both $PbSO_4$ and PbO_2 of the negative plate are converted to spongy lead.

In order to decrease its internal resistance and to increase its capacity, a series of parallel plates are alternately connected to the two electrodes provided with binding screws [Fig. 45(a)]. Insulating separators are placed between two consecutive plates to bring them closer towards each other without touching.

The *E.M.F.* of a fully charged cell is 2·2 volts which gradually falls to 2 volts and remains steady for a considerable time. Thus the cell is employed in cases where a *steady and strong* current is necessary. Due to the low value of internal resistance, a large current can be obtained from it. If a large number of plates are employed, the capacity of the cell will be increased. The capacity is expressed in **Ampere-hours.** Thus if the capacity of the cell is 45 Ampere-hours, then a steady current of 3 amperes can safely be drawn for 15 hours.

Precautions to be taken in using lead cells :

(1) *This cell should never be short-circuited,* for in that case a large current will flow, generating much heat and producing vigorous chemical action, due to which the plates will be *buckled* and *hard* $PbSO_4$ will be formed and the cell will be damaged.

(2) When the *E.M.F.* of the cell falls to 1·8 volts, it should no longer be used and charging should be made by employing lamp resistance as is shown in Fig. 39 of Art. 22(*c*) (*ii*).

(3) The battery to be charged should be inserted in the circuit *R so that the positive of the main should be joined with the positive of the battery* otherwise the battery will be damaged beyond remedy. The suitable charging current can be obtained by inserting a number of lamps in parallel and noting the current by introducing an ammeter in the circuit.

(ii) Alkali cells : In this cell, the positive plate is formed of hydroxides and higher oxides of Nickel which are contained in a perforated nickelled steel pocket. The negative plate is formed of finely divided iron and iron oxide, mixed with a certain percentage of cadmium, which are also contained in a perforated nickelled steel pocket. The plates are immersed in a 21% solution of *KOH* in water and a little lithium hydroxide contained in a nickel-plated steel box [Fig. 45(*b*)].

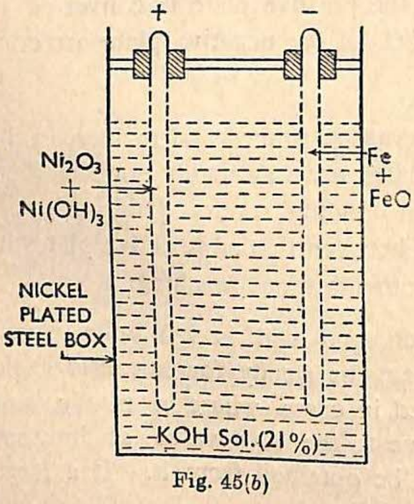

Fig. 45(*b*)

The *E.M.F.* of this cell, when steady, is 1·25 volts. This cell withstands greater rough-handling, over-charging, and greater rate of discharge than in the case of an acid cell. It is not destroyed by an accidental wrong charging or when left unused for a long time after charging.

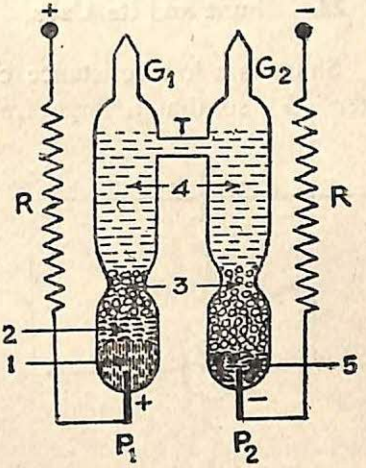

Fig. 46

(c) Standard cell.

Of the two standard cells which are available, Weston cadmium cell is usually employed. It consists of two glass vessels G_1 and G_2 joined together by a cross-tube T [Fig. 46]. Platinum wires P_1 and P_2 are sealed below the vessels G_1 and G_2 which respectively serve as the positive and negative electrodes. The positive electrode is pure mercury (1), above which there is a paste (2) of $CdSO_4$ and $HgSO_4$. Above this paste there are crystals of $CdSO_4$ (3). The negative electrode is an amalgam of Cadmium (5). Above this there are also crystals of $CdSO_4$ (3). Both the tubes contain saturated solution of $CdSO_4$ (4) above the $CdSO_4$ crystals. The solution extends above the connecting tube T and this solution is maintained saturated by $CdSO_4$ crystals. Arrangement is shown in Fig. 46.

E.M.F. of this cell is 1·0183 volts at 20°*C*, and at any temperature t°*C*, the *E.M.F.* is given by

$$E_t = 1{\cdot}0183 - {\cdot}0000406(t-20).$$

Violent jerks should never be given to the cell, for in that case some mercury from G_1 may go to G_2 through the connecting tube T causing a disturbance of chemical reaction. To guard against accidental short circuiting, high resistances R are joined in series so that the current drawn from the cell is very feeble.

This cell is employed as the *standard of E.M.F. and not for the supply of current.*

24. Shunt and its Uses.

Shunt is a low resistance connected parallel to a galvanometer (G) so that a large fraction of the main current may pass through the low resistance shunt S while a small fraction passes through the galvanometer and thereby the galvanometer is saved from damage. Thus the function of the shunt is to save the galvanometer from damage by reducing the current flowing through the galvanometer [Fig. 47].

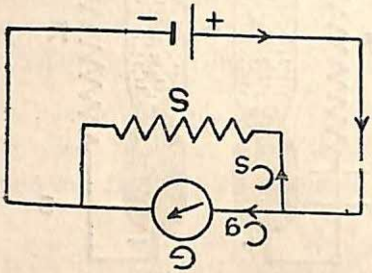

Fig. 47

Let, G =galvanometer resistance

S =shunt resistance

C_g=galvanometer current

C_s=current through the shunt

C =main current= $C_g + C_s$

Now current in a branch is inversely proportional to its resistance. Hence,

$$\frac{C_g}{C_s} = \frac{S}{G}; \qquad \text{or,} \qquad \frac{C_g}{C_g + C_s} = \frac{S}{S+G}$$

$$\text{or,} \quad \frac{C_g}{C} = \frac{S}{S+G}; \quad \text{or,} \quad C_g = C.\frac{S}{S+G} \quad \ldots \quad \ldots \quad (1)$$

$$\text{Similarly,} \quad C_s = C.\frac{G}{S+G} \quad \ldots \quad \ldots \quad (2)$$

By the term $1/n$th shunt we mean, that it is that shunt which will allow $1/n$th of main current C to pass through the galvanometer. Hence, $C_g = C/n$.

or, $$\frac{C}{n} = C.\frac{S}{S+G} \qquad \text{or,} \quad nS = S + G$$

or, $$S = \frac{G}{n-1} \qquad \dots \qquad \dots \qquad (3)$$

The relation (3) gives the shunt resistance which will allow $1/n$th of the main current to flow through the galvanometer.

25. Ammeters and Voltmeters.

(a) Ammeter : The complete picture of an ammeter can be obtained from Figures 48(*a*) and 48(*b*). It is a low resistance portable galvanometer inserted in series with the circuit to record the current flowing in it. The resistance of an ammeter is made very low by adding a low resistance shunt *R* parallel to it, so that the very current which we are going to measure may not alter by the insertion of ammeter. The coil *C* is capable of rotation about an axis pivoted in jewelled pivots. The coil *C* can rotate round a soft iron cylinder *L* [Fig. 48(*b*)] kept within the concave cylindrical pole pieces *N* and *S* of a permanent horse-shoe magnet [Fig. 48(*a*)]. The controlling couple is exerted by two hairsprings H_1 and H_2. One end of each hairspring is attached to the axis of rotation of the coil (*C*) while the other ends are attached to the two insulated studs S_1 and S_2 [Fig. 48(*a*)]. These springs

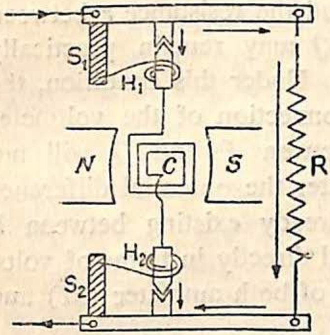

Fig. 48(*a*)

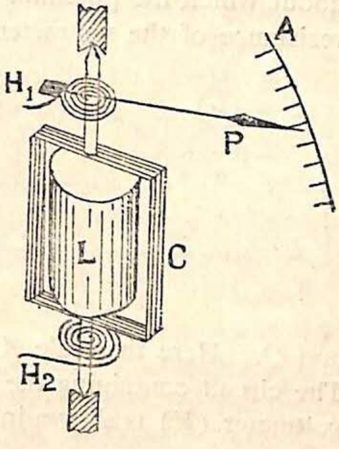

Fig. 48(*b*)

are wound in the opposite direction so that when the coil C rotates, one spring winds while the other spring unwinds itself. A pointer P [Fig. 48(b)] is attached to the axis of the coil and this pointer moves with the coil, over a scale A calibrated in amperes.

(b) **Voltmeter :** The construction of a voltmeter (V) is exactly the same as in the case of an ammeter, the only difference is that the shunt resistance R is removed and a very high resistance R' is added in series with the portable galvanometer [Fig. 49]. The voltmeter is to be joined in parallel between two points P and Q about which the potential difference is required and hence the resistance of the voltmeter should be high so that the equivalent resistance of the voltmeter and the resistance r between PQ may remain practically r. Under this condition, the connection of the voltmeter betwen P and Q will not alter the potential difference already existing between P and Q. Here the scale A is calibrated directly in terms of volts. The circuit containing the connections of both ammeter (M) and voltmeter (V) is shown in Fig. 49.

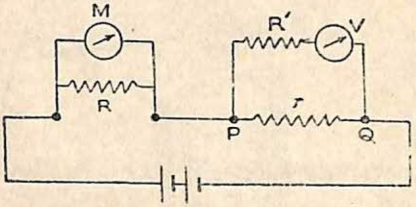

Fig. 49

26. General precautions to be taken in electrical experiments.

(i) All junctions must be made tight and to ensure good electrical contact, the ends which are at the junctions must be made clean by sand paper. To ensure the tightness of a wire in a binding screw, the wire should be pulled out gently to see whether it comes out or not.

(ii) Plugs of resistance boxes or of P.O. boxes must be inserted tight *by rotating the plug and at the same time pushing it downward,* otherwise an extra resistance will be inserted in the circuit for which we take no account.

(*iii*) Whenever a suspended coil galvanometer is to be introduced in a circuit, either a series high resistance (say of the order of 10,000 ohms.) or a very low resistance shunt should be applied to the galvanometer for safety.

(*iv*) A tapping key or a plug key should be joined parallel to a sensitive galvanometer so that the oscillation of the coil can be quickly stopped by generating an electromagnetic induced current in the coil by pressing the key at the moment when the spot of light passes through its rest position.

(*v*) In the tangent galvanometer experiment, the plane of the coil should be kept in the magnetic meridian which can be tested by observing the *equal deflection of the needle both with direct and reversed currents.*

(*vi*) In experiments with a voltameter, care should be taken to see that by the reversing of the current, *the galvanometer current is only reversed and not the current in the voltameter.*

(*vii*) Before inserting the plug in the key, be sure that the connections are according to the plan of the diagram, drawn on your rough note book.

(*viii*) When leaving the experimental table, be sure that all connections of your apparatus, lights, and fans are off.

(*ix*) Whenever a steady current is required, a storage cell, specially an alkali cell, should be used, but in Wheatstone bridge experiments (such as in Metre bridge and P. O. box) as well as in Carey Foster's bridge experiment, Leclanche's cell may be employed.

(*x*) Plugs should be inserted in the keys, *i.e.* current should be allowed to flow in the circuit so long as it is required. Continuous flow of currents will heat the circuit.

(*xi*) In suspended coil galvanometers, the deflection of the spot of light should lie between 8 to 16 cms. on a scale placed at a distance of one metre from the galvanometer mirror while in instruments where the tangent law is obeyed, the deflection should be kept at 45° to have minimum proportional error.

27. Wheatstone bridge principle and its application in (a) Metre Bridge (b) P. O. Box.

Wheatstone bridge principle :

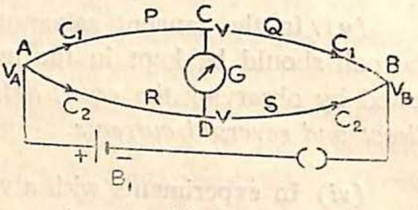

Fig. 50

If two conductors, *ACB* and *ADB* are connected parallel to a battery B_1 [Fig. 50] then for a point *C* on the conductor *ACB* there is a corresponding point *D* on the conductor *ADB* such that potentials $(=V)$ of these two points will be the same. If these two points *C* and *D* are joined by a galvanometer *G*, then no current will flow through it for want of any potential difference between *C* and *D*. If *P* and *Q* be the resistances of the portions *AC* and *CB* of the first conductor *ACB*, while *R* and *S* be the resistances of the portions *AD* and *DB* of the second conductor *ADB*, then according to Wheatstone bridge principle $P/Q=R/S$.

Proof : Let C_1 and C_2 be the currents in *ACB* and *ADB* while V_A and V_B are the potentials at *A* and *B*. By Ohm's law,

$$C_1=\frac{V_A-V}{P}=\frac{V-V_B}{Q} \quad \therefore \quad \frac{V_A-V}{V-V_B}=\frac{P}{Q} \qquad \ldots \ (1)$$

$$C_2=\frac{V_A-V}{R}=\frac{V-V_B}{S} \quad \therefore \quad \frac{V_A-V}{V-V_B}=\frac{R}{S} \qquad \ldots \ (2)$$

From (1) and (2) we get, $\frac{P}{Q}=\frac{R}{S}$ ... (3)

(a) Carey-Foster's bridge and its coversion to Metre

Bridge. Fig. 51 shows the arrangement of a Metre bridge or a Carey-Foster's bridge.

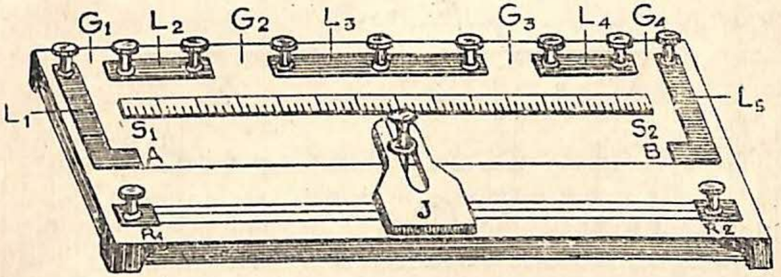

Fig. 51

Construction :—On a rectangular wooden board, five thick strips of copper L_1, L_2, L_3, L_4 and L_5 are fixed, leaving four gaps G_1, G_2, G_3 and G_4. Copper strips L_1 and L_5 are in the shape of L while the rest are straight. An one metre long fine uniform wire of manganin or german silver is soldered to the bent ends of strips L_1 and L_5. A jockey J moves over the metal rod R_1R_2. By pressing the button of the jockey, the rod R_1R_2 can be put in contact with any point of the wire AB and this point of contact can be noted from a metre scale S_1S_2, by the side of which an index mark on the jockey moves. By using all the four gaps, it can be employed as the Carey-Foster's bridge while if the two extreme gaps G_1 and G_4 are closed by two copper strips, then it serves as the Metre bridge.

Use : To use Carey-Foster's bridge as Metre bridge, the extreme gaps G_1 and G_4 are closed by two metal strips, while unknown resistance coils P and Q are connected to the binding screws by the sides of the gaps G_2 and G_3 [Fig. 51(*a*)]. One terminal of a galvanometer is joined to the binding screw R_1 of the rod R_1R_2 [Fig. 51], over which the jockey moves while the other terminal is joined to the binding screw B_5 at the middle of the strip L_3 [Fig. 51(*a*)]. A battery is joined to the binding screws B_3 and B_7 which are existing just outside the gaps G_2 and G_3. By moving the jockey, the different points of wire are put in contact with the galvanometer until no deflection is obtained. If l be the length of the wire (from the left-hand end) at which null point is obtained, then by Wheatstone bridge principle,

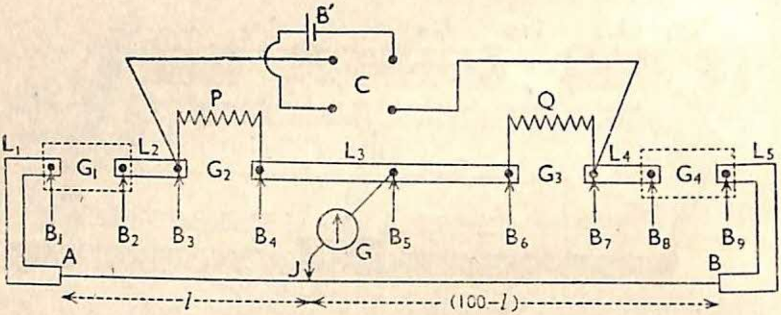

Fig. 51(*a*)

$$\frac{P}{Q}=\frac{\text{Resistance of length } l}{\text{Resistance of length } (100-l)}=\frac{\rho l}{(100-l)\rho}=\frac{l}{100-l} \quad \cdots \quad (4)$$

where ρ is the resistance per unit length of the Metre bridge wire. Measuring l from the scale, we can compare P and Q or we can find P, when Q is known.

(b) P. O. Box.

Construction : The actual plan of arrangements of a **P. O.**

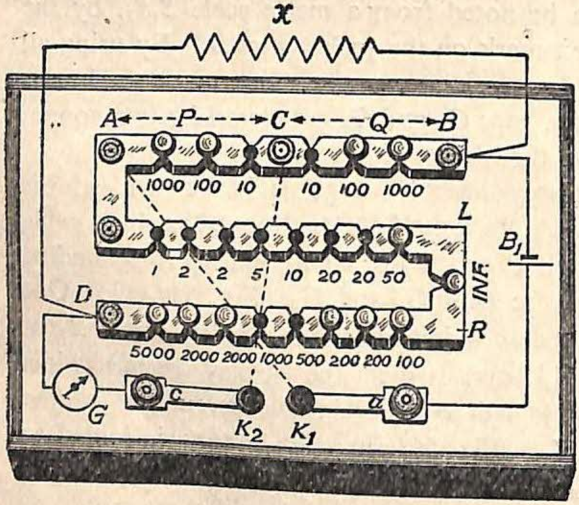

Fig. 52(*a*)

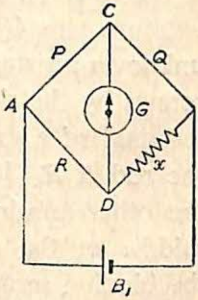

Fig. 52(*b*)

box is shown in Fig. 52(*a*) while the diagram of Wheatstone bridge is shown in Fig. 52(*b*). Three arms of a Wheatstone bridge, *viz.*, *Q*, *P* and *R* arms are given in the box while the fourth arm (*X*) is the unknown arm. *Q* and *P* are called ratio arms while the arm *R* is called the third arm. In the Figure 52(*a*) *BC* is the *Q* arm while *CA* is the *P* arm each containing resistances 10, 100 and 1000 ohms. The portion *ALD* is the '*R*' arm or third arm which contains a number of resistance coils, whose resistances lie between 1 and 5000 ohms and their total resistance is 11110 ohms. A galvanometer is to be joined between *D* (the junction of *R* and the unknown resistance *X*) and *c*. By pressing the key K_2, *c* will be connected to *C*, the junction of *P* and *Q* [connection between *C* and K_2 is shown in the Fig. 52 (*a*) by dots]. The battery is to be joined between *B* and *a*. By pressing the key K_1, *a* will be connected to *A* [connection between *A* and K_1 is shown in the Fig. 52 (*a*) by dots].

Use : (*i*) At first equal resistances (say 10, 10) are inserted in *Q* and *P* arms. Resistances in the third arm are then altered until we get the null point with a resistance R_1 (say). Then we have,

$$\frac{P}{Q}=\frac{R_1}{X} \qquad \therefore \quad X=\frac{Q}{P}R_1=\frac{10}{10}\cdot R_1=R_1 \text{ ohms.}$$

(*ii*) If we do not get the null point with any resistance, but opposite deflections are obtained with R_2 and (R_2+1), then *P* is made 100 ohms while *Q* is still kept at 10 ohms. Now the resistances in the third arm will have to be varied between $10R_2$ and $(10R_2+10)$. If we now get the null point for a resistance R_3 in the third arm, then the unknown resistance is given by,

$$X=\frac{Q}{P}R_3=\frac{10}{100}R_3=\frac{R_3}{10} \text{ ohms.}$$

(*iii*) If in this case also we do not get the null point with any resistance, but opposite deflections are obtained with R_4 and (R_4+1), then *P* is made 1000 ohms while *Q* is still kept at 10 ohms. Now the resistances in the third arm will have to be varied between $10R_4$ and $(10R_4+10)$. If we now get the null point for a particular resistance R_5 in the third arm, then,

$$X=\frac{Q}{P}R_5=\frac{10}{1000}R_5=\frac{R_5}{100} \text{ ohms.}$$

(*iv*) If at R_5 in the third arm, we do not get any null point but opposite deflections are obtained with R_6 and (R_6+1), then by a simple calculation we can find the exact resistance at which the null point will be obtained.

Let R_6 ohms in the third arm give a deflection of the spot of light by d_1 divisions in one direction on the galvanometer scale (say, towards right) while by the insertion of (R_6+1) ohms in the third arm, the spot of light shifts by d_2 divisions in the opposite direction (say, towards left). Then the extra resistance x, over R_6, required for no deflection, i. e., to decrease the deflection by d_1 divisions, is

$$x = \frac{d_1}{d_1 + d_2} \text{ ohms.} \qquad \therefore \quad X = \frac{R_6 + x}{100} \text{ ohms.}$$

28. General precautions to be taken in the experiments based on Wheatstone bridge principle.

(*i*) The bridge becomes most sensitive when the resistances in the four arms of the bridge are *equal*. Hence attempts should be made in this direction as far as possible.

For example, when a P. O. box is employed to measure a moderate resistance not exceeding 200 ohms (as in the case of verification of the laws of series and parallel resistances) the resistance in the ratio arms should be 10 : 10 and 10 : 100. The ratio 10 : 1000 will give large difference in the resistances in the four arms and hence the bridge becomes so much insensitive that even a change of 5 ohms resistance in the third arm will cause no appreciable change in the balanced condition of the bridge. Hence it is unprofitable to extend up to the ratio 10 : 1000.

Again if the resistance to be measured lies between 200 and 1000 ohms (as in the case of the resistance of an electric lamp in cold) then for greater accuracy it is desirable to work with the ratio 100 : 100 and 100 : 1000.

(*ii*) For Wheatstone bridge work, a *cell of any kind may be employed*. If the *E.M.F*. of the cell changes with time, then there will be equal changes in the potential for the pair of corresponding points in the $(P-Q)$ arms and in the $(R-S)$ arms. Hence zero potential difference between the two ends of the galvanometer will remain unaltered causing no change in the null point.

(*iii*) The *E.M.F.* of the battery employed *must not be very high,* otherwise standard resistance coils employed in the circuit will be damaged by the production of much heat in them.

(*iv*) The battery key should be kept *closed only for that minimum time which is necessary to find a null point;* otherwise a continuous flow of current in the standard resistance coils in the circuit, will heat them unequally due to their different temperature coefficient of resistances and as a consequence, the balance of the bridge will be disturbed. The battery key should be kept open from two to three minutes before the next determination of the null point is taken up.

(*v*) To avoid the effect of self-inductance (if any) of the resistance coils, the *battery key should be closed first* and then the galvanometer key. If the battery key is closed first, the current in the circuit will quickly assume its maximum value (i) causing no change of current in the circuit and hence the induced *E.M.F.* in the circuit $\left(\text{which is} = L\frac{di}{dt}\right)$ due to the change of current in it, may be nil.

(*vi*) If the galvanometer employed to detect the balanced condition of the bridge be very sensitive (such as a mirror galvanometer) then either a high resistance in series with the galvanometer or a low resistance shunt parallel to the galvanometer should be applied until an approximate null point is obtained. Then to get the correct null point, the sensitiveness may be increased either by reducing the series resistance to zero or by making the shunt resistance equal to infinity, *provided the former arrangement was not sufficiently sensitive.*

(*vii*) No changes in the balanced condition of the bridge will be observed on interchanging the positions of the galvanometer and the battery. This indicates that the position of a null point is independent of the resistances of the galvanometer and the battery, though the sensitiveness of the bridge is affected by their resistances. For greater sensitiveness, the resistances of the battery and the galvanometer should be *low* (the resistance of the galvanometer should not exceed 50 ohms) and the galvanometer or the battery whichever has the higher resistance should be placed between the junctions of two arms having greater resistance and the junction of two arms having smaller resistance.

(*viii*) Very high or very low resistances cannot be measured with Wheatstone bridge for the bridge becomes too much insensitive for these resistances.

29. Verification of the laws of Parallel and Series resistances by using a P. O. Box.

Theory : When two resistances r_1 and r_2 are joined in parallel [Fig. 53(*a*)], their equivalent resistance R is given by,

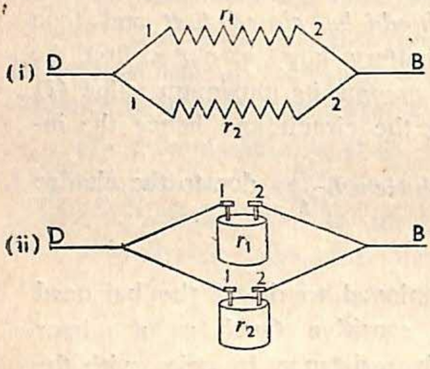

Fig. 53 (*a*)

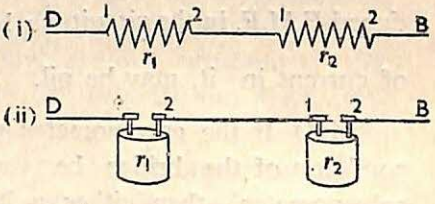

Fig. 53(*b*)

$$\frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}\,;\quad\text{or,}\quad R=\frac{r_1r_2}{r_1+r_2}\qquad\cdots\qquad\cdots\quad(1)$$

Again, when the resistances r_1 and r_2 are joined in series [Fig. 53(*b*)], their equivalent resistance R' is given by,

$$R'=r_1+r_2\qquad\ldots\qquad\ldots\qquad\ldots\quad(2)$$

By employing a P. O. box, each of the two individual resistances r_1 and r_2 and also their equivalent resistances R_1 and R_2 when joined in parallel and in series respectively are to be measured. We shall see that R and R' calculated by the relations (1) and (2), in which parallel and series laws are respectively assumed, agree with R_1 and R_2 found out by actual experiment. Thus both the parallel and series laws are verified.

Resistances are measured on the principle of Wheatstone bridge (viz. $P/Q=R/X$) which is adopted in the P. O. box [Fig. 54(*b*)]. From which the unknown resistance (X) is given by,

$$X=\frac{Q}{P}R \qquad \cdots \qquad \cdots \qquad (3)$$

Connection of the apparatus : Connections are shown in Fig. 54(*a*) while the diagram of Wheatstone bridge is shown in Fig. 54(*b*). Unknown resistance X is connected at the beginning (B) of the first arm BC (*i.e.* of the Q arm) and at the end (D) of the third arm ALD (*i.e.* of the R arm) of the P.O. box. Battery is to be connected at the end of the ratio arms P and Q. For this purpose, one terminal of the battery is connected to B while its other terminal is connected to the binding screw '*a*' of the key K_1, which is in metallic connection with the point A as is shown on the box by drawing a white line which joins A and K_1 (A may remain joined with K_1 or K_2, which vary from one box to another). On pressing the key K_1 connections will

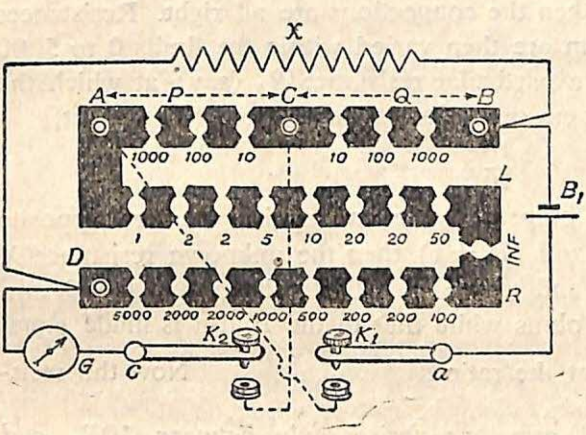

Fig. 54(*a*)

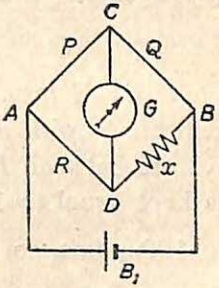

Fig. 54(*b*)

be established between '*a*' and A. One terminal of the galvanometer is to be connected at D while its other terminal is to be joined to the binding screw '*c*' of the key K_2, which is in metallic connection with the point C as is shown on the box by a white line joining C and K_2. On pressing the key K_2, connections will be established between '*c*' and C, the junction of the P and Q arms.

Procedure : (*i*) Resistances of values 10 ohms and 10 ohms are inserted in the ratio arms Q and P respectively so that $Q/P=1$. At first, the highest resistance (viz., infinity or 5000 ohms) and the lowest resistance (viz., 0) are alternately inserted in the third arm of the box and the directions of galvanometer deflections are noted by pressing the battery key K_1 first and then the galvanometer key K_2. If opposite deflections are obtained then the connections are all right. Resistances (R) in the third arm are then varied within the limits 0 to 5000 ohms until we get a particular resistance R_1 (say) at which the galvanometer shows no deflection. Hence from (3) we get,

$$X=\frac{10}{10}\times R_1=R_1 \text{ ohms.}$$

(*ii*) If instead of getting the null point we get opposite deflections with R_2 and (R_2+1) then the unknown resistance X will lie between R_2 and (R_2+1). The resistance in the Q arm is kept equal to 10 ohms while that in the P arm is made equal to 100 ohms, so that the ratio $\frac{Q}{P}=\frac{10}{100}=\frac{1}{10}$. Now the resistances in the third arm are *varied only between* $10R_2$ *and* $(10R_2+10)$ until we get no deflection at R_3, when

$$X=\frac{Q}{P}R_3=\frac{1}{10}R_3.$$

N.B. [If a resistance between $10R_2$ and $(10R_2+10)$ inserted in the third arm gives a strong deflection of the galvanometer, then it should be inferred that the resistances in P and Q arms have been reversed. In that case, 10 ohms should be replaced by 100 ohms and 100 ohms should be replaced by 10 ohms.]

(*iii*) Again, if we get no null point but opposite deflections within a range of one ohm, then the ratio should be made 1/100 (*i.e.* $Q=10$ ohms and $P=1000$ ohms) until we get no deflection at a particular resistance. If in this case also we get no null point, but opposite deflections within a range of one ohm, then the particular resistance, which will give no deflection at the ratio 1/100, can be calculated by employing ordinary principle of proportion [for details see Art. 27(*b*), item (*iv*)].

(*iv*) The second resistance (r_2) as well as the equivalent resistances R_1 and R_2 when r_1 and r_2 are joined in parallel and in series* respectively, are similarly determined. We shall see that the equivalent resistances R and R' calculated from r_1 and r_2, by employing parallel and series laws [the relations (1) and (2)] respectively, agree with R_1 and R_2 which verify the two laws.

Precautions : (*i*) To avoid the effect of self-inductance of resistance coils, if any, the battery key should be closed first and then the galvanometer key.

(*ii*) The plugs of the box are to be *kept tight by rotating the plugs* and contact points should be kept clean.

(*iii*) If a storage cell is employed, then a rheostat should be joined in series with the cell to save the cell as well as standard resistance coils from damages.

(*iv*) If the range of the resistances in the third arm with lower ratio does not tally with that obtained with higher ratio, then either the plugs are loose or the resistances of the box are imperfectly calibrated. After making plugs tight, if this discrepancy still exists, then the resistance in the third arm at higher ratio should be taken.

(*v*) If the galvanometer gives the deflection in the same direction for all resistances, then the connections are to be considered wrong.

(*vi*) A record should always be made of the resistance R which gives no deflection as well as of the resistances $(R+1)$ and $(R-1)$ which give opposite deflections.

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*Resistances r_1 and r_2 will be joined in parallel when their 1st terminals are joined to D and 2nd terminals are joined to B [Fig. 53(*a*)]. Series connection between r_1 and r_2 will be obtained when terminals 2 and 1 of r_1 and r_2 respectively are joined by a wire while the terminal 1 of r_1 is joined to D and the terminal 2 of r_2 is joined to B [Fig. 53(*b*)].

Experimental data :

[Numerical figures given in the table are for illustrations only]

TABLE I

Res. in the fourth arm (unknown) in ohms.	Value of Q in ohms.	Value of P in ohms.	Ratio Q/P	Resistance in the third arm in ohms. (R)	Galvanometer deflection.	Nature of resistance in the R-arm, in comp. with the unknown res. (X).	Unknown resistance (X) in ohms.
r_1	10	10	1	5000	right	too high	r_1 lies between 60 and 61 ohms
				0	left	,, low	
				200	right	,, high	
				20	left	,, low	
				100	right	,, high	
				40	left	,, low	
				50	left	,, low	
				60	slightly left	slightly low	
				61	,, right	,, high	
	10	100	$\frac{1}{10}$	608	right	high	r_1 lies between 60·5 and 60·6 ohms.
				607	right	,,	
				606	slightly right	slightly high	
				605	slightly left	slightly small	
				604	left	small	
	10	1000	$\frac{1}{100}$	6055	slightly left	slightly small	r_1 = 60·56 ohms
				6056	no deflection		
				6057	slightly right	slightly high	
r_2							
R_1							
R_2							

TABLE II

r_1 in ohms	r_2 in ohms	Connections made with r_1 and r_2	Equivalent resistance of r_1 and r_2 in ohms.		Inference
			Experimental	Calculated	
....	....	parallel	$\ldots = R_1$	$\ldots. = R$	Parallel law is verified.
		Series	$\ldots = R_2$	$\ldots. = R'$	Series law is verified

Oral Questions and their Answers

1. What is a P. O. box and why is it so called ?

It is a compact form of Wheatstone bridge in which three arms are given. It is so named because it was originally intended for service in the British Post Office for measuring resistances of telegraph wires.

2. What is the principle under which the P- O. box acts ?

Wheatstone bridge principle [See Art. 27]

3. Can you measure very high or low resistances by the box ?

No ; for the bridge becomes insensitive, *i.e.* the galvanometer will show no deflection within a certain range of resistances. The bridge would be most sensitive when the resistances of the four arms are equal.

4. Will the null point be altered, if the battery and the galvanometer be interchanged or some resistances are joined in series with them ?

No ; for it can be shown that when the bridge is exactly balanced, *i.e.* the galvanometer current is zero, then the relation ($P/Q = R/X$) is independent of the resistances of battery and galvanometer circuit. But for a slight want of balance, the galvanometer deflection will be large if the resistances of the galvanometer and battery are very low. Also the battery or the galvanometer, whichever has the greater resistance, is to be joined between the junction of the two arms having greater resistances and the junction of the two arms having lower resistances.

5. Which of the two keys you will close first and why ?

To avoid the effect of self-inductance of the resistance coils, in the box battery circuit should be closed first and then the galv. circuit.

6. Will the null point change, when a cell, whose E.M.F. is gradually decreasing, is employed by you ?

No, for the distribution of potential in the two parallel branches will change equally maintaining the null point.

7. If the resistance coils of your box be calibrated at 20°C., will they give the same value at 30°C. ?

No, for the resistance of metals increases with temperature.

8. Sometimes the limits of the resistances found with the lower ratio (say 10 : 10) do not coincide with that obtained with the higher ratio. What are the reasons for this and what should be your procedure then ?

The reasons for this are—(*i*) loose fitting of the plugs in the gaps and (*ii*) imperfect calibration of the resistance coils.

When such cases arise, the plugs of the box should be made tight by *twisting* and the values obtained with the higher ratio should be accepted.

9. Can you use your box to measure resistance which are respectively higher and lower than the highest and the lowest resistances available in the box ?

Yes ; if the value of the ratio Q/P is made smaller or greater than unity then we shall be able to measure low or high resistance respectively.

10. What is the unit of resistance ?

Ohm ; it is the resistance of a conductor in which 1 ampere current flows, when a P. D. of 1 volt is applied at its ends.

30. Determination of the resistance of a galvanometer by Thomson's method.

Theory : Wheatstone bridge principle, as adopted in P. O. box, may be employed to determine the resistance of a galvanometer by inserting it in the fourth arm BD of bridge and by employing a key K_2 only in the galvanometer circuit CD [Fig. 55].

A small potential difference obtained against a resistance r, inserted in a separate circuit, should be applied between A and B. When the conjugate condition, viz. $\frac{P}{Q}=\frac{R}{G}$ i.e. $G=\frac{Q}{P}R$. is satisfied, the current in the branch CD becomes zero and the current in all other branches of the bridge

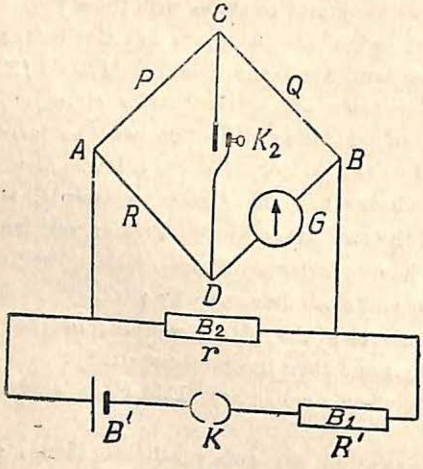

Fig. 55

will remain unaltered causing no change in the galvanometer deflection, whether the key K_2 in the branch CD is kept open or closed.

Thus the determination of the resistance G of the galvanometer involves the determination of the value of the resistance R in the third arm of the P.O. box (for a given value of the ratio of Q and P) for which there will be no *change* in the galvanometer deflection whether the key K_2 is kept open or closed.

Connection of the apparatus : Connections are shown in Fig. 56, the details of which are given below :

(*i*) A separate circuit is made with a battery B', a key K and two resistance boxes B_1 and B_2. A high resistance R' (the value of R' should be of the order of 200 ohms or more depending on the sensitiveness of the galvanometer) is inserted in the box B_1 while a *very low resistance* r is inserted in the box B_2.

(*ii*) The terminals of the box B_2 are joined to the extremities A and B of the ratio arms P and Q respectively.

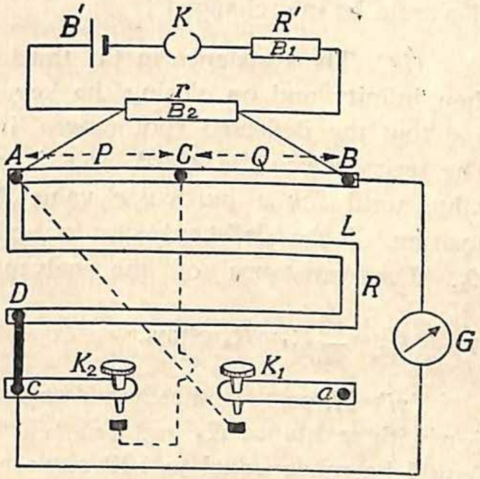

Fig. 56

(*iii*) The binding screw c of the key K_2 and the end point D of the third arm of the P.O. box are connected by a *thick* wire and by such connection, the key K_2 only is inserted in the usual galvanometer circuit CD.

(*iv*) The galvanometer whose resistance G is required is connected between B and D which constitutes the fourth arm of the P. O. box. The key K_1 is kept inoperative.

7. If the resistance coils of your box be calibrated at 20°C., will they give the same value at 30°C. ?

No, for the resistance of metals increases with temperature.

8. Sometimes the limits of the resistances found with the lower ratio (say 10 : 10) do not coincide with that obtained with the higher ratio. What are the reasons for this and what should be your procedure then ?

The reasons for this are—(*i*) loose fitting of the plugs in the gaps and (*ii*) imperfect calibration of the resistance coils.

When such cases arise, the plugs of the box should be made tight by *twisting* and the values obtained with the higher ratio should be accepted.

9. Can you use your box to measure resistance which are respectively higher and lower than the highest and the lowest resistances available in the box ?

Yes ; if the value of the ratio Q/P is made smaller or greater than unity then we shall be able to measure low or high resistance respectively.

10. What is the unit of resistance ?

Ohm ; it is the resistance of a conductor in which 1 ampere current flows, when a P. D. of 1 volt is applied at its ends.

30. Determination of the resistance of a galvanometer by Thomson's method.

Theory : Wheatstone bridge principle, as adopted in P. O. box, may be employed to determine the resistance of a galvanometer by inserting it in the fourth arm BD of bridge and by employing a key K_2 only in the galvanometer circuit CD [Fig. 55].

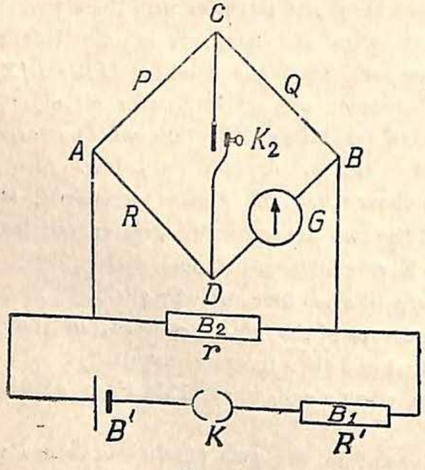

Fig. 55

A small potential difference obtained against a resistance r, inserted in a separate circuit, should be applied between A and B. When the conjugate condition, viz. $\frac{P}{Q}=\frac{R}{G}$ *i.e.* $G=\frac{Q}{P}R$. is satisfied, the current in the branch CD becomes zero and the current in all other branches of the bridge will remain unaltered causing no change in the galvanometer deflection, whether the key K_2 in the branch CD is kept open or closed.

Thus the determination of the resistance G of the galvanometer involves the determination of the value of the resistance R in the third arm of the P.O. box (for a given value of the ratio of Q and P) for which there will be no *change* in the galvanometer deflection whether the key K_2 is kept open or closed.

Connection of the apparatus : Connections are shown in Fig. 56, the details of which are given below :

(*i*) A separate circuit is made with a battery B', a key K and two resistance boxes B_1 and B_2. A high resistance R' (the value of R' should be of the order of 200 ohms or more depending on the sensitiveness of the galvanometer) is inserted in the box B_1 while a *very low resistance* r is inserted in the box B_2.

(*ii*) The terminals of the box B_2 are joined to the extremities A and B of the ratio arms P and Q respectively.

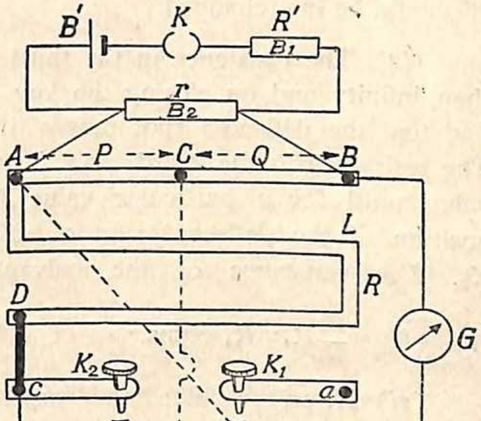

Fig. 56

(*iii*) The binding screw c of the key K_2 and the end point D of the third arm of the P.O. box are connected by a *thick* wire and by such connection, the key K_2 only is inserted in the usual galvanometer circuit CD.

(*iv*) The galvanometer whose resistance G is required is connected between B and D which constitutes the fourth arm of the P. O. box. The key K_1 is kept inoperative.

Procedure : (*i*) When no current flows in the circuit, *i.e.* when the key K is not closed, the spot of light is brought at one end of the galvanometer scale.

(*ii*) Resistances 10 and 10 ohms are respectively inserted in the ratio arms Q and P. The value of r in the box B_2 is made zero while the value of R' in the box B_1 is kept near about 200 ohms or more depending on the sensitiveness of the galvanometer. The key K is now closed and the value of r is gradually increased until the spot of light is deflected *near to the other end* of the scale.

N.B. [If, on closing the key K, the spot of light is found to be deflected in a direction outside the scale and not inside the scale, then the wires connecting the two poles of the battery B' should be interchanged.]

(*iii*) The resistance in the third arm is first made zero and then infinity and on closing the key K_2 in each case, we shall find that the deflected spot moves in the opposite directions. The resistance in the third arm is then increased from zero value until for a particular value R_1 there is no change of position of the deflected spot on closing or opening the key K_2. The resistance of the galvanometer is then given by

$G=\frac{Q}{P}R_1=\frac{10}{10}R_1=R_1$ ohms.

(*vi*) If, on the other hand, we get opposite changes of deflection with resistance R_2 and (R_2+1) in the third arm, then P should be made equal to 100 ohms while Q should be still kept equal to 10 ohms. [At this time r should be changed to have nearly the same steady deflection as before.]. The resistances in the third arm are then changed between $10R_2$ and $(10R_2+10)$ until at a particular resistance R_3 we get no change of deflection on closing or opening the key K_2. The galvanometer resistance is then given by, $G=\frac{Q}{P}R_3=\frac{10}{100}\times R_3=\frac{R_3}{10}$ ohms.

(*v*) If for the ratio, $Q/P=10/100$ we get opposite deflections with resistances R_4 and (R_4+1) then Q/P should be made equal to 10/1000 and a suitable resistance R_5 between $10R_4$ and $(10R_4+10)$ should be found out for which there will be no change of the deflection (steady deflection should be made the same as before by changing r) on closing or opening the key K_2. The galvanometer resistance is then given by,

$$G=\frac{Q}{P}R_5=\frac{10}{1000}R_5 \text{ ohms.}$$

Experimental Data :

[Make a table similar to the TABLE I of Expt. 29, and introduce the following changes there :—

(*i*) In the heading of 6th column write 'change of galvanometer deflection' *instead of* 'galvanometer deflection'.

(*ii*) Write *G in place of* r_1 in the first column.

(*iii*) Omit the columns containing r_2, R_1 and R_2.]

Precautions : (*i*) The plugs of the box should always be kept tight by *rotating* each plug by hand and *not by striking its head.*

(*ii*) As the method is very insensitive owing to a very small current in the bridge, the initial deflection of the spot of light should be made from one end of the scale to its other end nearly.

(*iii*) The magnitude of the change of deflection when the key K_2 is closed depends on the resistance in the branch *cD*. Hence greater sensitiveness will be expected if *D* and *c* are joined by a thick wire.

(*iv*) Due to the insensitiveness of the bridge, no change of the deflection of the spot will be noticed when the values of the resistance (R) in the third arm lie within a certain range. In that case, the *mean of the two extreme resistances* of the range (for which there is no change of galvanometer deflection) should be accepted as the proper value of R.

(*v*) The key K in the battery circuit should be a plug key ; for a steady current in the bridge is necessary before the key K_2 is closed.

(*vi*) For each value of the ratio of Q/P the value of r in the box B_2 should be changed to have *nearly the full scale deflection* of the spot.

Oral Questions and their Answers

1. What do you mean by the term 'galvanometer resistance' ?

By the term 'galvanometer resistance' we mean the resistance of the coil of wire, which may be fixed or free through which current to be measured flows.

2. What is the harm if you shunt your galvanometer to reduce its deflection ?

In that case we get the resistance of the shunted galvanometer $\left(=\frac{SG}{S+G}\right)$ and not the resistance of the galvanometer alone.

3. When do you expect no change of galvanometer deflection on pressing the key K_2 and why ?

When the conjugate condition viz. $\frac{P}{Q}=\frac{R}{G}$ is satisfied we expect no change of initial galvanometer deflection on pressing the key K_2 ; for in that case, there will be no current in the branch CD whether the key K_2 is kept closed or open causing no change of current in the four arms of the bridge and hence no change of galvanometer deflection.

4. What will happen if the battery is directly connected in the bridge between A and B ?

As the galvanometer deflection cannot be reduced by shunt, the application of the full E. M. F. of the cell in the bridge will produce more than full-scale deflection of the spot of light.

5. Why do you make an initial full-scale deflection of the spot of light ?

Sensitiveness of the method will increase if greater current is passed through the bridge. Hence maximum current required to make a full-scale deflection of the spot of light was passed in the bridge.

6. What is the best method of measuring the galvanometer resistance ?

Galvanometer resistance is best measured by clamping its coil and placing it in the fourth arm (BD) of the P. O. box while a second galvanometer should be placed in the arm CD to detect the balance.

31. Measurement of the internal resistance of a cell by Mance's method (as modified by Lodge).

Theory : The principle of Wheatstone bridge as adopted in P.O. box may be employed to find the internal resistance of a cell. The cell whose internal resistance (X) is required is to be placed in the fourth arm BD of the bridge while an ordinary tapping key K_1 is to be placed in the branch AK_1B where usually a battery is connected [Fig. 57]. The galvanometer G is connected as usual in the branch CD through a condenser F which eliminates steady current in the galvanometer circuit.

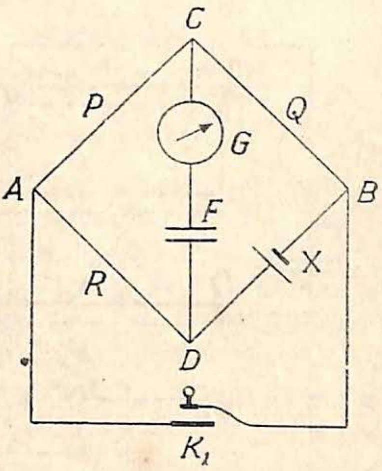

Fig. 57

A permanent potential difference exists between A and B as well as between C and D. So long as the conjugate condition is not satisfied, the opening or closing of the key K_1 will cause a change in the potential difference between C and D. This change of potential difference between C and D will alter the charge on the condenser plates producing a momentary *kick* in the galvanometer. When the conjugate condition, viz., $\frac{P}{Q}=\frac{R}{X}$ or, $X=\frac{Q}{P}R$ is satisfied the potential difference existing between C and D will be independent of that existing between A and B. Hence the closing or opening of the key K_1 will cause no change in the potential difference between C and D producing no *kick* of the galvanometer.

The experiment then consists in adjusting the resistances (R) in the third arm of the P.O. box until there is no galvanometer kick on closing or opening the key K_1.

Connection of the apparatus : The details of the plan of connections are shown in Fig. 58.

(*i*) The cell of internal resistance X is connected through a plug key K between B and D, which is the fourth arm of the bridge.

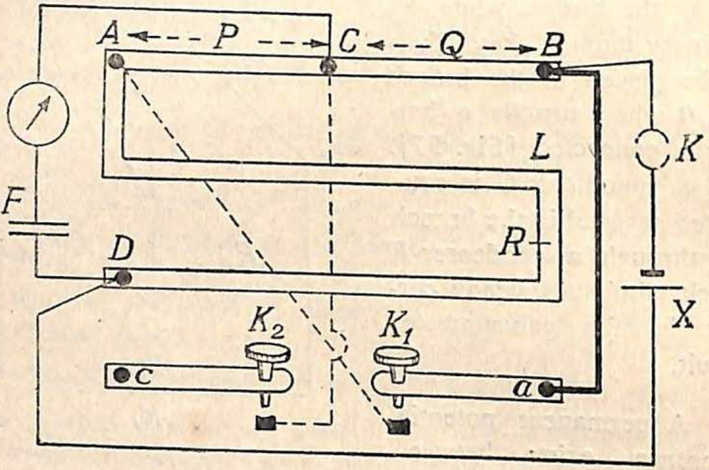

Fig. 58

(*ii*) The galvanometer G and the condenser F (of about 1/3 microfarad capacity) are directly connected between C and D without including the key K_2 of this circuit.

(*iii*) A thick wire is connected between B and '*a*' by which the key K_1 alone is included in the branch BK_1A where a battery is usually placed.

Procedure : (*i*) At first resistances 100 and 100 ohms are respectively inserted in the two ratio arms P and Q of the P. O. box and then the key K is closed.

[**N.B.** In the case of a Daniel cell, whose internal resistance is high and in which polarisation is absent, the resistance in the ratio arms should be 10 and 10 ohms.

On the other hand, if the internal resistance is low or the cell polarises easily the initial resistances in the two ratio arms should be high making each equal to 100 ohms].

(*ii*) The resistance in the third arm is made zero and then infinity and on closing the key K_1 in each case we shall find an opposite kick of the galvanometer spot of light. The resistance in the third arm is then increased from zero value until for a particular value R_1 there is no kick of the galvanometer spot of light on closing or opening the K_1. The resistance of the cell is then given by, $X=\frac{Q}{P}R_1=\frac{100}{100}R_1=R_1$ ohms.

(*iii*) If, on the other hand, we get opposite kick of the galvanometer spot of light with resistances R_2 and (R_2+1) in the third arm then P should be made 1000 ohms while Q should still be kept equal to 100 ohms. The resistances in the third arm are then changed between $10R_2$ and $(10\,R_2+10)$ until for a particular resistance R_3 we get no kick of the galvanometer spot of light, on closing or opening the key K_1. The resistance of the cell is then given by,

$$X=\frac{Q}{P}R_3=\frac{100}{1000}R_3=\frac{R_3}{10}\text{ ohms.}$$

(*iv*) If for the ratio, $\frac{Q}{P}=\frac{100}{1000}$ we get opposite kick of the gavanometer spot with resistances R_4 and (R_4+1) then Q should be made equal to 10 ohms while P should be made equal to 1000 ohms and a suitable resistance R_5, between $10R_4$ and $(10R_4+10)$ should be found out for which there will be no kick of the galvanometer spot of light, on closing or opening the key K_1. The resistance of the cell is then given by,

$$X=\frac{10}{1000}R_5=\frac{R_5}{100}\text{ ohm.}$$

Experimental data :

[Make a table similar to the TABLE I of Expt. 29 and introduce the following changes there :—

(*i*) In the heading of the 6th column write 'Direction of galvanometer kick' *instead of* 'galvanometer deflection'.

(*ii*) Write X *in place of* r_1 in the first column.

(*iii*) Omit the columns containing r_2, R_1 and R_2].

Precautions : (*i*) If the cell polarises easily then the initial resistances in the ratio arms should be made each equal to 100 ohms so that the polarisation may be minimum. Higher resistances in the ratio arms also reduce the current strength in the circuit by which both the resistance coils and the cell are saved from damage.

(*ii*) The wire employed to connect the cell in the fourth arm of the P. O. box must be short and thick, otherwise a resistance higher than the battery resistance will be measured.

(*iii*) Greater changes of potential difference and hence greater kick of galvanometer spot will occur when the current flowing in the branch BK_1A on closing the key K_1, is large. Hence to ensure greater sensitiveness, the wire connecting B and *'a'* should be thick and short.

Oral Questions and their Answers

1. What do you mean by the term 'internal resistance of a cell' ?

When current flows within the cell from the low to the high potential plate, the medium existing between the plates offer, to the current a resistance known as the 'internal resistance of the cell.'

2. What factors determine the internal resistance of a cell ?

The factors which influence the internal resistance of a cell are,

(*i*) conductivity of medium existing between the plates,
(*ii*) area of the immersed portion of the plates,
(*iii*) the distance between the plates.

3. What do you mean by the term 'Polarisation of the cell' and what are its remedy ?

H^+ ions which deposit on the neutral layer of H_2 molecules on the high potential plate produce an E.M.F. which is opposite to the main E.M.F. causing a decrease of current strength. This defect of the cell is known as 'Polarisation'.

It is removed by (*i*) chemical means—in which H_2 molecules on the high potential plate are converted to water by some oxidising agents, such as MnO_2, conc. HNO_3 etc. (*ii*) Electro-chemical means—in which ions of the same metal as that of the high potential plate are deposited on the high potential plate and deliver their charges to it instead of any H^+ ion. This is employed in Daniell cell.

4. What do you mean by the term E.M.F. of a cell and what are constant cells ?

The E.M.F. of a cell is the potential difference that exists between the two plates of the cell when the plates are not joined externally by a wire.

Constant cells are those whose E M.F's remain constant even when a current is drawn from them. Daniell cell, Storage cell are examples of constant cells.

5. Does the E.M.F. of a cell depend on the dimensions of the plates of the cell ?

No ; only the internal resistance of the cell depends on its dimensions. E.M.F. of a cell depends on the nature of the materials with which the cell is constructed.

6. What is the mechanism by which each plate of the primary cell acquires a potential ?

When the plates of a cell are introduced into the exciting liquid, each plate acquires a charge and hence a potential by the transference of ions either from the plate to the exciting liquid or from the exciting liquid to the plate due to the inequality of osmotic and solution pressures. This potential which each plate acquires is known as electrode potential.

7. Why do you connect '*B*' and '*a*' by a thick wire ? The change of P. D. between *C* and *D* and consequently the magnitude of the kick of the galvanometer spot depends on the change of current in the circuit BK_1A when the key K_1 is closed. Hence *B* and '*a*' are joined by a low resistance *thick and short wire* so that the change of current on closing the key K_1 may be greater.

1. What will you do if the condenser is not available ?

In that case, a very high resistance is to be joined in series with the galvanometer to reduce its deflection to the desired value and instead of observing a kick of the galvanometer spot we shall see a change of galvanometer deflection on closing the key K_1.

9. Is the internal resistance of a cell constant ?

No, the internal resistance of a cell depends on the current in it.

32. Determination of the end-corrections of the metre bridge wire.

Theory : In the metre bridge apparatus, small resistance exist at each end of the bridge wire due to (*i*) not negligible resistances of the copper strips at the two ends, (*ii*) bad soldering at the two ends of the wire, (*iii*) non-coincidence of the two ends of the wire with the zero and hundred marks of the metre scale. These resistances at the two ends of the bridge wire are known as the *end-errors* of the metre bridge wire.

Let the resistances which exist at the left and right end of the wire be respectively equal to the resistances of lengths λ_1 and λ_2 cms. of the bridge wire. If two known resistances P and Q of ratio, $r=P/Q$ be respectively inserted in the left and right gaps of the metre bridge and a null point is obtained at a distance l_1 cm. from the left end of the wire then by Wheatstone bridge principle,

$$r=\frac{P}{Q}=\frac{l_1+\lambda_1}{100-l_1+\lambda_2} \qquad \ldots \qquad \ldots \qquad \ldots \quad (1)$$

Let now the resistances P and Q in the left and right gaps be interchanged and a new null point is obtained at a distance l_2 cm. from the left end of the wire. When we again get,

$$\frac{1}{r}=\frac{Q}{P}=\frac{l_2+\lambda_1}{100-l_2+\lambda_2} \qquad \ldots \qquad \ldots \qquad \ldots \quad (2)$$

By solving the relations (1) and (2) we get,

$$\lambda_1=\frac{l_1-rl_2}{r-1} \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (3)$$

$$\lambda_2=\frac{rl_1-l_2}{r-1}-100 \qquad \ldots \qquad \ldots \qquad \ldots \quad (4)$$

By employing the relations (3) and (4) we can find λ_1 and λ_2.

Connections of the apparatus : If the metre bridge is provided with four gaps then the two extreme gaps G_1 and G_4 should be tightly closed by two copper strips, while resistances P (=10 ohms) and Q (=1 ohm) are to be inserted in the two middle gaps G_2 (towards left) and G_3 (towards right) respectively [∵ The ratio $r=P/Q=10:1$]. *A* battery B' is connected to the binding screws B_3 and B_7 through a commutator C. One terminal of the galvanometer G is connected to the binding screw B_5 while the other terminal is connected to the jockey *J* which can slide over the bridge wire *AB*. The plan of connections is shown in Fig. 59.

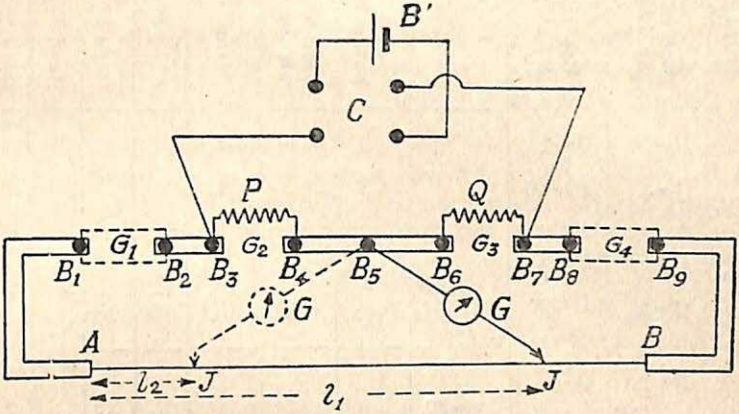

Fig. 59

Procedure : (*i*) The jockey *J* is first put in contact with the end *A* and next with the end *B* of the bridge wire *AB*. When we shall observe opposite deflections of the galvanometer. This shows the correctness of the connections of the apparatus.

(*ii*) By trial, the null point is obtained at one end of the wire at a certain distance from the left end. This null point is determined both for direct and reversed currents and let the mean distance of this null point from the left end be l_1 cm.

N.B. [Null point will be shifted towards that gap of the bridge in which the resistance inserted is lower].

(*iii*) The resistances *P* and *Q* in the gaps G_2 and G_3 are now interchanged and a new null point is obtained at the other end of the wire both for direct and reversed currents. Let the mean distance of this null point from the left end of the wire be l_2 cm.

(*iv*) Knowing l_1, l_2, and the ratio, r $(=P/Q=10)$ we can calculate λ_1 and λ_2 from the relations (3) and (4) respectively.

(*v*) The experiment is repeated to find λ_1 and λ_2 with other ratios of *P* and *Q* (say $r=P/Q=20:1$; $r=P/Q=30:1$). The mean values of λ_1 and λ_2 are then found out.

Experimental data :

No. of obs.	Res. in left gap. in ohms.	Res. in right gap, in ohms	Ratio = $r=\frac{P}{Q}$	Null points in cm. with			λ_1 in cm.	λ_2 in cm.	Mean λ_1 in cm.	Mean λ_2 in cm.
				direct current	reversed current	Mean				
1	$P=10$	$Q=1$	$r=10$	...	...	...(l_1)	...	...		
	$Q=1$	$P=10$		...	...	..(l_2)				
2	$P=20$	$Q=1$	$r=20$	....	...	....(l_1)	...	...	...	...
	$Q=1$	$P=20$		...	...	...(l_2)				
3	$P=30$	$Q=1$	$r=30$	...	...	...(l_1)	...	...		
	$Q=1$	$P=30$		...	...	....(l_2)				

Calculations :

$$\lambda_1=\frac{l_1-rl_2}{r-1}= \qquad \dots \qquad = \qquad \dots \text{ cm.}$$

$$\lambda_2=\frac{rl_1-l_2}{r-1}-100 = \qquad \dots \qquad = \qquad \dots \text{ cm.}$$

Precautions : (*i*) *P* and *Q* should never be made *equal* in that case there will be no appreciable change of null point on interchanging the resistances.

(*ii*) Connections of resistances *P* and *Q* in the two gaps should be effected by *thick and short* copper wires.

(*iii*) If a mirror galvanometer is employed then it should be shunted by a low resistance before the null point is attained. When approximate null point is obtained the shunt may be removed to increase the sensitiveness, if it is found to be necessary.

Oral Questions and their Answers

1. Why do you call your apparatus as metre bridge ?

Because in this form of Wheatstone bridge a uniform wire of one metre long is employed.

2. What is the end-error of the metre bridge ?—[See Theory]

3. Is it necessary that the wire should be of same material and uniform cross-section ?

Yes ; for the resistance of a wire of length l and cross-section α is given by $R=Sl/\alpha$. When the specific resistance S of the material of the wire and its cross-section α are constants, the resistance of the wire will be proportional to its length, which is assumed here for the purpose of calculation.

4. Will the null-point obtained for the given values of P and Q change if your bridge wire be replaced by another uniform wire of different material and cross-section ?

No ; as the resistance per unit length ρ remains the same throughout the whole length of the new wire, the relation $\frac{P}{Q}=\frac{l\rho}{(100-l)\rho}$ remains independent of the value of ρ.

5. Is it necessary to put a resistance in series with the battery ?

If the battery be of low resistance and capable of sending a strong current in the circuit (such as a storage cell) then the current in the circuit should be reduced by inserting a series resistance in the battery circuit so that the resistance coils and their insulations may not be damaged.

6. If in spite of the correct connections of the apparatus, you observe the galvanometer deflections in the same direction at the two extreme ends of the wire, then what should be your conclusion ?

In this case, one of the resistances in the two gaps of the bridge is too large in comparison with the other. If the null point is observed beyond the right end of the wire then the resistance inserted in the left gap is too high which should be changed to a suitable lower value.

7. When the bridge becomes most sensitive ?

The bridge becomes most sensitive when the resistances in the four arms of the bridge are equal.

8. Can you employ your metre bridge to measure a very high resistance ?

No ; when two high resistances are inserted in the two gaps of the metre bridge, practically the whole current flows through the bridge wire causing the bridge much more insensitive.

33. Determination of the resistance of a given wire by applying Wheatstone bridge principle and adopting end corrections and hence to find the specific resistance of the material of the given wire.

Theory : If R be the resistance of a wire of length L and diameter d, then its specific resistance S is given by the relation,

$$R = S\frac{L}{\pi d^2/4} \text{ ; or, } S = \frac{R\pi d^2}{4L} \qquad \ldots \qquad \ldots \quad (1)$$

Measuring R by a metre bridge, L by a scale, and d by a screw gauge, S can be found out. Resistance can be determined by the application of Wheatstone bridge principle adopted in metre bridge, *viz.*,

$$\frac{\text{Res. in the left gap}}{\text{Res. in the right gap}}$$

$$= \frac{l \text{ [length of the bridge wire from left] } + \lambda_1}{(100-l) \text{ [length of the bridge wire from right] } + \lambda_2} \quad \ldots \quad (2)$$

Here the end errors at the left and right ends of the bridge wire are equivalent to the resistances of λ_1 and λ_2 cms. of the bridge wire. To find λ_1 and λ_2. two unequal resistances P and Q (of ratio, $r = P/Q$) are to be respectively inserted in the left and right gaps of the metre bridge. If l_1 cm. be the distance of the null point from the left end, with P and Q in the left and right gap resptctively and l_2 cm. be the distance of null point when P and Q are interchanged in the gaps, then it can be shown that,

$$\lambda_1 = \frac{l_1 - rl_2}{r-1} \text{ cm. } \ldots (3) \text{ ; } \lambda_2 = \left(\frac{rl_1 - l_2}{r-1} - 100\right) \text{ cm.} \qquad \ldots \quad (4)$$

Connections of the apparatus : If the apparatus is provided with four gaps then two extreme gaps G_1 and G_4 of the apparatus should be closed by copper strips. When determining the specific resistance of a wire of unknown resistance R, the wire should be connected to the left G_2 while a resistance box P, containing fractional ohms, should be connected to the right gap G_3 (Fig. 60). A battery is connected through a commutator C to the binding screws existing *just outside* the gaps G_2 and G_3. One terminal of a galvanometer is connected to the jockey J while its other terminal is connected to the binding screw existing at the middle of the copper strip L_3. If a mirror galvanometer is employed, then a rheostat should be joined in series with the

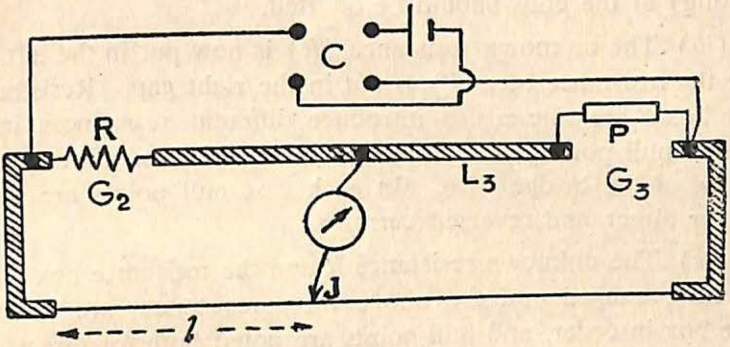

Fig. 60

battery and the galvanometer should be shunted by a low resistance. Usually a Leclanche's cell and a portable galvanometer will serve the purpose. The connections are shown in Fig. 60.

Procedure : (*i*) Before inserting the unknown resistance (R) and the resistance box (P) in the gaps G_2 and G_3 respectively, the two resistances of value $10\,\Omega$ $(=P)$ and $1\,\Omega$ $(=Q)$ are inserted in the left and right gaps (gaps G_2 and G_3 respectively) of the metre bridge and the positions of the null point with direct and reversed currents are found out, and then the mean of these two null points (l_1) is determined. The resistances in the two gaps are then interchanged and in a similar manner mean null point (l_2) is determined. Knowing l_1, l_2 and $r=(P/Q=10:1)$, λ_1 and λ_2 are calculated from (3) and (4) respectively. Again the values of λ_1 and λ_2 are found out by repeating the experiment, first with $20\,\Omega$ $(=P)$ in the left gap and $1\,\Omega$ $(=Q)$ in the right gap (when $r=P/Q=20$) and then with P and Q interchanged. The mean values of λ_1 and λ_2 are found out from these two sets of observations.

(*ii*) About 1 cm. length of the given wire at its two ends is bent at right angles to the rest of the wire. When this given wire is to be joined to a gap, these bent portions at the two ends are to be kept inside the binding screws. When the length of the wire is to be measured, the *distance between the two bends should only be measured* and these two bent portions (each of about 1 cm. long) at the ends should be omitted.

(*iii*) The unknown resistance (R) is now put in the left gap while the resistance box (P) is put in the right gap. Resistances in the box P are altered to introduce different resistances in it, at which null points are obtained at about 45 cms., 50 cms. and 55 cms. of the bridge wire. In each case null points are noted both for direct and reversed currents.

(*iv*) The unknown resistance R and the resistance box P are then interchanged and the above three resistances are inserted in the box in order, and null points are noted both for direct and reversed currents. The resistance which gave null point near 45 cms. in the former case, will now give the null point near about 55 cms. after interchange.

(*v*) The value of the unknown resistance is calculated in each case by the relation (2) and the mean (R) is obtained.

(*vi*) The length (L) of the wire *between the two bends* is measured by a metre-scale (*i.e.* the length of the wire is measured by omitting about 1 cm. bend at each end).

(*vii*) The diameter (d) of the wire is determined at various places by a screw gauge and the mean value is taken.

Experimental data :

(A) *To find* λ_1 *and* λ_2 :—

TABLE I

[Make a table as in the case of expt. 32, with two ratios, viz., $P/Q=10$ and $P/Q=20$ only.]

(B) *Length* (L) *of the wire* :—

$$\text{Distance between the two bends at the ends} = \frac{\cdots + \cdots + \cdots}{3}$$

$$= \ldots \text{cm.}$$

(C) *Diameter (d) of the wire :—*

TABLE II

[Make a chart for the screw gauge as is given on p. 20. Part I and measure diameter at least in six different places.]

(D) *Determination of the resistance (R) of the given wire :—*

TABLE III

[Numerical figures in the table are for illustrations only].

No. of obs.	Resistance in the left gap in ohms.	Resistance in the right gap in ohms.	Null points in cm. (l) with, direct current	reversed current	Mean l in cm	Unknown Resistance R in ohms.	Mean R in ohms.	Specific resistance, $S=\frac{R\pi d^2}{4L}$
	(unknown)	(known)						
1.	R	1·1	45·1	45·1	45·1	·9035		
2.	,,	...	...	...	...	...		
3.	,,	...	....	...	...	...		
	(known)	(unknown)					...	....
4.	1·1	R	54·5	54 5	54·5	·9183		ohm.-cm.
5.	...	,,	...	...	...	....		
6.	...	,,	...	...	....	...		

Calculations :

(a) *λ_1 and λ_2 calculations :—*

$$\lambda_1=\frac{l_1-rl_2}{r-1}= \quad ... \quad = \quad ... \quad \text{cm.}$$

$$\lambda_2=\frac{rl_1-l_2}{r-1}-100= ... \quad = \quad ... \quad \text{cm.}$$

(b) 'R' calculations :

Formula is,

$$\frac{\text{Res. in the left gap}}{\text{Res. in the right gap}}=\frac{l+\lambda_1}{100-l+\lambda_2}$$

(i) $R=$ ... = ... = ... ohms.

(ii) etc.

is to be joined to a gap, these bent portions at the two ends are to be kept inside the binding screws. When the length of the wire is to be measured, the *distance between the two bends should only be measured* and these two bent portions (each of about 1 cm. long) at the ends should be omitted.

(*iii*) The unknown resistance (R) is now put in the left gap while the resistance box (P) is put in the right gap. Resistances in the box P are altered to introduce different resistances in it, at which null points are obtained at about 45 cms., 50 cms. and 55 cms. of the bridge wire. In each case null points are noted both for direct and reversed currents.

(*iv*) The unknown resistance R and the resistance box P are then interchanged and the above three resistances are inserted in the box in order, and null points are noted both for direct and reversed currents. The resistance which gave null point near 45 cms. in the former case, will now give the null point near about 55 cms. after interchange.

(*v*) The value of the unknown resistance is calculated in each case by the relation (2) and the mean (R) is obtained.

(*vi*) The length (L) of the wire *between the two bends* is measured by a metre-scale (*i.e.* the length of the wire is measured by omitting about 1 cm. bend at each end).

(*vii*) The diameter (d) of the wire is determined at various places by a screw gauge and the mean value is taken.

Experimental data :

(A) *To find* λ_1 *and* λ_2 :—

TABLE I

[Make a table as in the case of expt. 32, with two ratios, viz., $P/Q=10$ and $P/Q=20$ only.]

(B) *Length* (L) *of the wire* :—

Distance between the two bends at the ends$=\dfrac{\cdots+\cdots+\cdots}{3}$

$=\ldots$cm.

(C) *Diameter (d) of the wire :—*

TABLE II

[Make a chart for the screw gauge as is given on p. 20. Part I and measure diameter at least in six different places.]

(D). *Determination of the resistance (R) of the given wire :—*

TABLE III

[Numerical figures in the table are for illustrations only].

No. of obs.	Resistance in the left gap in ohms.	Resistance in the right gap in ohms.	Null points in cm. (l) with, direct current	reversed current	Mean l in cm	Unknown Resistance R in ohms.	Mean R in ohms.	Specific resistance, $S=\frac{R\pi d^2}{4L}$
	(unknown)	(known)						
1.	R	1·1	45·1	45·1	45·1	·9035		
2.	,,	...	...	...	...	...		
3.	,,	...	....	...	...	...	...	....
	(known)	(unknown)						ohm.-cm.
4.	1·1	R	54·5	54 5	54·5	·9183		
5.	...	,,	...	...	...	....		
6.	...	,,	...	...	....	...		

Calculations :

(*a*) λ_1 *and* λ_2 *calculations :—*

$$\lambda_1=\frac{l_1-rl_2}{r-1}= \;\cdots\; = \;\cdots\; \text{cm.}$$

$$\lambda_2=\frac{rl_1-l_2}{r-1}-100=\cdots \;=\; \cdots\; \text{cm.}$$

(*b*) *'R' calculations :*

Formula is,

$$\frac{\text{Res. in the left gap}}{\text{Res. in the right gap}}=\frac{l+\lambda_1}{100-l+\lambda_2}$$

(*i*) $R=\;\ldots\;=\;\ldots\;=\;\ldots$ ohms.

(*ii*) etc.

(*c*) *Sp. res. calculation* :—

$$S=\frac{R\pi d^2}{4L}=\ \cdots\ =\ \cdots\ \text{(ohm.-cm.)}$$

Precautions : (*i*) The diameter of the wire should be measured very carefully after proper consideration of the instrumental error of screw gauge.

(*ii*) To have minimum proportional error in the measurement of *R*, the null points should lie between 45 and 55 cm. of the bridge wire.

(*iii*) The plugs of the resistance box are to be kept tight by *twisting* the head of the plug.

(*iv*) Battery key should be kept closed so long as it is required, otherwise unnecessary heating will change the resistance of the circuit.

Oral Questions and their Answers

1. Define Specific resistance and state its unit..

Specific resistance of a material is the resistance of the material of unit length and of unit area of cross-section. Its unit is (ohms-cm.).

2. Does the specific resistance of a wire change with its (*i*) length, (*ii*) diameter, (*iii*) material and (*iv*) temperature ?

Specific resistance of a *given material* does not change with length or diameter of the wire, for in the definition, the resistance of the material having a fixed dimension is called sp. resistance. But sp. resistance changes with the material and for the same material it is different at different temperatures.

3. In measuring resistance, why do you (*i*) maintain the null point within the range of 45 to 55 cms., (*ii*) interchange the resistance in the gaps ?

(*i*) It can be shown by calculus that when the null point is kept at or near about 50 cms. of the bridge wire, the proportional error in the measurement of the unknown resistance will be minimum.

[See item (*b*) Part I. p. 4]

(*ii*) Interchange is made to eliminate the error arising out of the non-coincidence of the index mark on the jockey with the actual point of contact of the wire. It also minimises the error due to non-uniformity of the bridge wire.

4. Why do you note the null point with direct and reversed currents ?

To eliminate the effect of thermo-current if any in the circuit. Due to the existence of junctions of different materials, a thermo-current will flow when a temperature difference will be established between the junctions.

5. Will you get an accurate result with a long or with a short wire?

Long wire is desirable for a small error in measuring the resistance or length will not affect the result materially.

6. What is the end error of the metre bridge.

[*See* the 'theory' of Expt. 32].

7. Does the resistances of the battery or galvanometer affect your result? No. [*See* Ans. of Q. 4 Expt. 29]

8. What do you mean by the term conductivity of a material?

It is the reciprocal of sp. resistance and its unit is, $(ohm^{-1}-cm.^{-1})$.

34. Determination of the average resistance per unit length of the metre bridge wire by Carey Foster's method.

Connections of the apparatus: The plan of connections

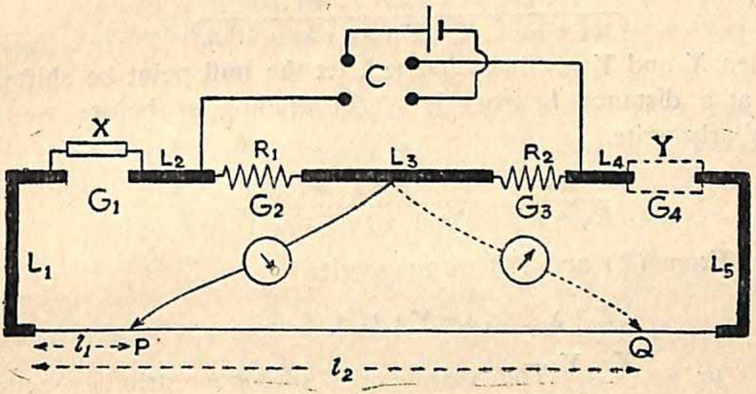

Fig. 61

is shown in Fig. 61. A resistance box (X) is connected to the extreme left gap G_1 while a copper strip (Y) is joined to the extreme right gap G_4.

Two resistance coils R_1 and R_2 (each equal to 1 ohm.) are respectively joined to the gaps G_2 and G_3. Terminals of the battery (usually a Leclanche's cell) are joined to the two binding screws *just outside the gaps* G_2 and G_3 through a commutator C.

The terminals of the galvanometer (usually a portable one) are joined to the jockey and to the binding screw at the middle of the copper strip L_3. If a mirror galvanometer is employed, then a rheostat should be joined in series with the battery and a shunt should be joined in parallel to the galvanometer to save the galvanometer from damage.

Theory : Let the null point be obtained at P at a distance l_1 from the left end of the wire, when connections are made with a certain resistance X in the extreme left gap G_1, copper strip Y in the extreme right gap G_4, R_1 in the gap G_2 and R_2 in the gap G_3. Hence we have,

$$\frac{R_1}{R_2}=\frac{X+\lambda_1+l_1\rho}{Y+\lambda_2+(100-l_1)\rho}. \quad \dots \quad \dots \quad (1)$$

Here λ_1 and λ_2 are the end corrections at the left and right ends of the bridge wire and ρ is the resistance per unit length of the bridge wire. The relation (1) may be written as,

$$\frac{R_1}{R_1+R_2}=\frac{X+\lambda_1+l_1\rho}{X+Y+\lambda_1+\lambda_2+100\rho}. \quad \dots \quad (2)$$

When X and Y are interchanged, let the null point be shifted to Q at a distance l_2 from left. Proceeding as before we may similarly write,

$$\frac{R_1}{R_1+R_2}=\frac{Y+\lambda_1+l_2\rho}{X+Y+\lambda_1+\lambda_2+100\rho} \quad \dots \quad (3)$$

From (2) and (3) we may write,

$$X+\lambda_1+l_1\rho=Y+\lambda_1+l_2\rho$$

or, $\rho=\frac{X-Y}{l_2-l_1}$. The resistance Y of copper strip is practically zero and hence,

$$\rho=\frac{X}{l_2-l_1} \quad \dots \quad \dots \quad \dots \quad \dots \quad (4)$$

If the copper strip Y is first placed in the left gap (instead of the resistance X) and the resistance X in the right gap, then $\rho=X/(l_1-l_2)$. Hence we may write $\rho=X/(l_2\sim l_1)$ ... (5)

The equation (5) may be employed to find ρ, the resistance per unit length of the bridge wire.

Procedure : (*i*) Two resistances (each equal to 1 ohm.) are inserted in the two middle gaps G_2 and G_3. At first, zero resistance is inserted in the resistance box (X) in the extreme left gap G_1, so that the resistances in both the extreme gaps G_1 and G_4 are zero. This time we should get the null point near the middle of the wire (for, $R_1=R_2=1$ ohm). If instead of getting the null point at the middle, we get it at a point after crossing one end (say right end), then we infer that the resistance R_1 in G_2 (the left of the two middle gaps) is wrong which should be changed. Thus by ascertaining the correct conditions of the apparatus, a suitable resistasce X is applied in the resistance box inserted in the gap G_1 (extreme left gap).

(*ii*) Now resistances inserted in the box X are changed until the first null point is obtained at a point which is 2 to 5 cms. from the end (the null point will be on that side, at which the resistance box X is placed). The null points are noted both for direct and reversed currents and their mean value is found out.

(*iii*) Now the resistances in the box X are to be altered in steps to shift the null points by steps of about 5 cms. towards the middle and in each case the null points are noted both for direct and reversed currents and their mean value is found out. Four such observations are made when the resistance box X is in the extreme left gap G_1 only. The distance of last null point should not exceed 20 cm. from the left end of the bridge wire.

(*iv*) Now the resistance box and the copper strip in the two extreme gaps are interchanged and again four different null points are noted, both with direct and reversed currents, *by inserting those resistances in the box X serially as they were inserted when the box was in the gap G_1* and the copper strip was in the gap G_4.

(*v*) ρ is calculated by using the relation (5), from each pair of null points, obtained for a particular resistance introduced in the two extreme gaps alternately. The mean of several values of ρ obtained from different pairs of null points is the average resistance per unit length.

Experimental data :

[*Numerical figures in the table are for specific illustratios only*].

$R_1 = R_2 =$ 1 ohm.

No. of obs.		Resistances in ohms. applied in,		Null points in cm. with			$(l_2 \sim l_1)$ in cm.	$\rho = X/(l_2 \sim l_1)$ in ohms. per cm.	Mean ρ in ohms per cm.
		extreme left gap	extreme right gap.	direct current	reversed current	Mean			
1.	(*a*)	2·1 (X)	0	4	4·2	4·1 (l_1)	92	·022	
	(*b*)	0	2·1(X)	96	96·2	96·1(l_2)			
2.	(*a*)	1·8(X)	0	9·1	9·3	9·2(l_1)	82	·022	
	(*b*)	0	1·8(X)	91 3	91·1	91·2 (l_2)			
3.	(*a*)								...
	(*b*)								
4.	(*a*)								
	(*b*)								

N.B. [Observations (*a*) are taken first.
Observations (*b*) are taken later.]

Calculations :

(*i*) $$\rho = \frac{X}{(l_2 \sim l_1)} = \frac{2{\cdot}1}{(96{\cdot}1 \sim 4{\cdot}1)} = {\cdot}022 \text{ ohms per cm.}$$

(*ii*) etc.

Precautions : (*i*) At the beginnisg, both X and Y should be made zero to see whether the null point is near the middle of the bridge wire (when $R_1 = R_2$). If the null point is found beyond the extreme right end of the bridge wire, then the resistance R_1 is wrong and *vice versa*.

(*ii*) The ratio of the two resistances R_1 and R_2 should be equal to one or nearly equal to one, otherwise null points may not be obtained within the bridge wire. For greater sensitiveness of the bridge, the value of each of the two resistances R_1 and R_2 should be equal to one ohm.

(*iii*) For first observation, the value of X should be so chosen that the two balance points should be very near to the two ends of the bridge wire. By this $(l_2 \sim l_1)$ would be greater and more accurate value of ρ, would be obtained. For the successive observations, the value of X should be altered so as to shift the null point gradually towards the middle of the wire by steps of about 5 cm. but not exceeding 20 cm.

Oral Questions and their Answers

1. Can you perform your experiment with two unequal resistances of any ratio inserted in the two middle gaps ?

If the resistance R_2 in the gap G_3 be very high in comparison with the resistance R_1 in the gap G_2, then the null point will shift towards that end of the bridge wire (left end) at which the low resistance R_1 is situated even when X and Y are kept at zero value. If the resistance box X having some resistance be placed in the gap G_1 while zero resistance be placed in the gap G_4 the null point will be further shifted towards the left end and no null point will be obtained in the bridge wire. Thus the experiment cannot be performed with any ratio of R_1 and R_2. Hence the ratio of R_1 and R_2 should be 1 or nearly 1 having each individual resistance a value nearly equal to that of 50 cm. length of the bridge wire *i.e.* nearly 1 ohm. so that the bridge may be sensitive due to the existence of nearly equal resistances in the four arms of the Wheatstone bridge.

2. Will the presence of end error in the bridge, affect your result in any way ?

It is evident from the theory that ρ is independent of the end errors.

3. Why do you prefer a longer length between two null points obtained before and after the interchange of resistances in the two extreme gaps ?

As ρ is not the same at all parts of the wire, greater accuracy in the average value of resistance per unit length will be obtained, if longer length is covered between two null points.

4. How is the resistance per unit length (ρ) of the wire, related to its specific resistance (S) ?

The relation between ρ and S is given by, $\rho=\frac{4S}{\pi d^2}$, where d is the diameter of the wire. Thus by measuring ρ and d, we can find S and *vice-versa*. The increase in the diameter (d) of the wire will cause a decrease in the resistance per unit length.

5. Why do you note the null points with direct and reversed currents ?

To eliminate the effect of any thermo-current flowing in the circuit.

6. What is the harm, if ρ is determined by measuring resistance of the bridge wire by a P. O. box and dividing that resistance by the length of the wire ?

The method is not accurate but only a rough method. For accuracy. Carey-Foster's bridge method should be adopted.

7. Does the value of ρ determined by you is the same at every point of the wire ?

Usually not, for the wire cannot be accurately uniform. What we measure is the average resistance per unit length.

8. Can you compare two nearly equal resistances by this method ? If so, what is the limitation ?

Yes ; from the theory we see that $(X-Y)=\rho(l_2-l_1)$ and hence knowing ρ and determining l_2 and l_1 we can find the small difference between two resistances X and Y. Thus the method is useful for the standardisation of a given resistance.

The difference between the two resistances must be below the total resistance of the bridge wire.

35. Comparison of the values of two low resistances by the drop of potential method.

Connections of the apparatus : The plan of connections is shown in Fig. 62. Two low resistances X and R, provided with current and potential leads, are respectively inserted in the gaps G_1 and G_2 of the metre bridge. The current leads C_2 and C_3 of X are connected to the binding screws on the two sides of the gap G_1, while its potential leads P_1 and P_2 are respectively joined to the binding screws A and B of the four-way key. The current leads C_4 and C_5 of R are connected to the binding screws on tde two sides of the gap G_2, while its potential leads P_3 and P_4 are respectively joined to the binding screws C and D of the four-way key. The connecting wires from C_2 and C_5, which are joined to the metre bridge should be *long enough* to get the balance points for A and D just at the extremities of the bridge wire. Sometimes due to the presence of sufficient resistance at the soldered ends of the bridge wire, the potentials corresponding to

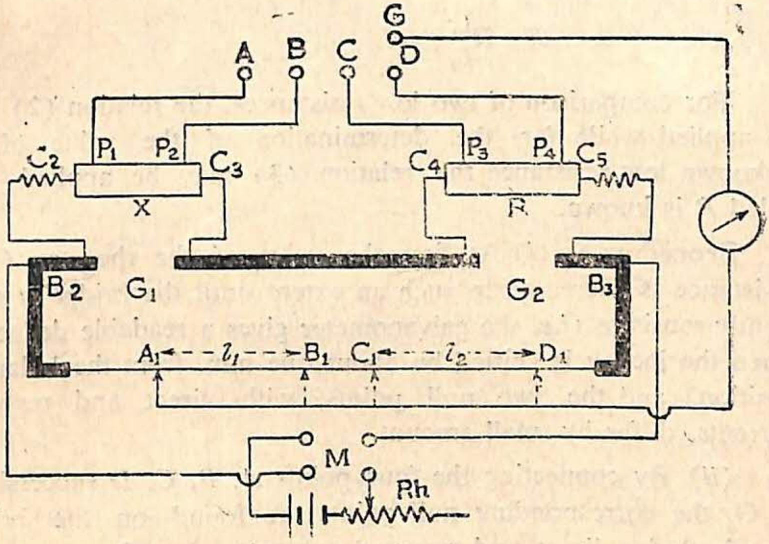

Fig. 62

P_1 and P_4 go outside the bridge wire. In this case, the connecting wires from C_2 and C_5 should be made long enough to bring the null points corresponding to P_1 and P_4 just at the ends of the bridge wire.

The galvanometer is joined between the jockey and the binding screw G of the four-way key. The battery (preferably two alkali cells in series) is connected to the binding screws B_2 and B_3 through a series rheostat Rh having a sufficient resistance and a commutator M.

Theory : Let i_1 and i_2 be the strengths of the current which are flowing in the low resistance branch and bridge wire branch respectively. As the points A, B, C and D of low resistance branch are equipotentials to the points A_1, B_1, C_1 and D_1 of the bridge wire branch, we have,

$$i_1X = i_2(l_1\rho)\ ;\ i_1R = i_2(l_2\rho). \qquad \cdots \qquad \cdots \qquad (1)$$

Here, $l_1 = A_1B_1$; $l_2 = C_1D_1$ and ρ =resistance per unit length of the bridge wire.

Taking ratio of two equations given in (1), we get,

$$\frac{X}{R} = \frac{l_1}{l_2} = m \text{ (say)} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

$$\text{or,} \quad X = R\frac{l_1}{l_2} = mR. \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

For comparison of two low resistances, the relation (2) may be applied while for the determination of the value of an unknown low resistance the relation (3) may be applied provided *R* is known.

Procedure : (*i*) At first the value of the rheostat (*Rh*) resistance is decreased to such an extent until the bridge is sufficiently sensitive (*i.e.* the galvanometer gives a readable deflection when the jockey is shifted by about one mm. from the balanced position) and the two null points, with direct and reversed currents, differ by small amount.

(*ii*) By connecting the four points *A, B, C, D* successively to *G*, the corresponding null points are found on the bridge wire both for direct and reversed currents. Let the corresponding mean null points be at A_1, B_1, C_1 and D_1 which are found out and from them, $l_1 (= A_1B_1)$ and l_2 $(= C_1D_1)$ are determined. Thus, *X*/*R* is calculated by employing the relation

$$\frac{X}{R} = \frac{l_1}{l_2}.$$

(*iii*) The resistances *X* and *R* are then interchanged *i.e.* *R* is placed in the left gap while *X* is placed in the right gap. By proceeding as in (*ii*) the ratio $\frac{R}{X} = \frac{l_1}{l_2}$; or, $\frac{X}{R} = \frac{l_2}{l_1}$ is now calculated.

(*iv*) The operation (*ii*) and (*iii*) are repeated by increasing the length of the connecting wires from C_2 and C_5 slightly, so that the null points for *A* and *D* may shift a bit away from the ends of the bridge wire (*i.e.* towards the centre of the wire). Calculating *X*/*R* in each case, its mean value is taken. From this mean value of *X*/*R*, *X* can be found out when *R* is known.

Experimental data :

[Numerical figures in the table are for illustrations only].

Res. of connecting wires from C_2 and C_5	Resistances in ohms. inserted in,		Points joined to G for balance,	Balance points in cm. with			Intercept on the bridge wire in cm.	value of, $\frac{X}{R}$	Mean $\frac{X}{R}=m$
	left gap	right gap		direct current	reversed current	Mean			
Small	X =un-known	R(...) =second unknown (or known)	A	1·1	1·3	1·2(A_1)	$l_1=A_1B_1$	$\frac{X}{R}=\frac{l_1}{l_2}$	...
			B	27·2	27·4	27·3(B_1)	=26·1		
			C	30·1	30·4	30·3(C_1)	$l_2=C_1D_1$	=·4	
			D	95·5	95·7	95·6(D_1)	=65·3		
	R	X	A B C D					$\frac{X}{R}=\frac{l_2}{l_1}$ =...	
High	R	X						$\frac{X}{R}=\frac{l_2}{l_1}$ =	
	X	R						$\frac{X}{R}=\frac{l_1}{l_2}$ =...	

Calculations :

$\frac{X}{R}=m$; $\therefore$ $X=mR=$ ... $=$ ... ohms.

Precautions : (*i*) Sometimes null points for the two extreme ends *A* and *D* of the resistances go outside the bridge wire. In that case, the length of wires between C_2B_2 and C_5B_3 should be *increased to such an extent* so as to get the null points for *A* and *D* at the left and right extreme ends of the bridge wire respectively.

(*ii*) For greater sensitiveness, a fairly strong current is to be passed through the circuit and hence to avoid unnecessary heating, the *circuit should be kept closed only for that minimum time which is necessary to get a null point* and then the circuit should be kept open for at least two or three minutes to find the next null point.

For this purpose it is convenient to introduce a plug key in the battery circuit (not shown in the Fig. 62) in addition to the commutator.

(*iii*) To avoid the error due to non-uniformity of the bridge wire, the experiment should be repeated by interchanging the two resistances X and R.

Oral Questions and their Answers

1. What quantity is measured here and why do you prefer this method to any other available methods ?

Low resistance is measured here, by the drop of potential method. Wheatstone bridge method can be employed to measure moderate resistances only but not low resistance due to two reasons : (*i*) the resistance of the connecting wires become comparable with that of the resistance to be measured. (*ii*) Wheatstone bridge becomes very much insensitive when the low resistance is inserted in one arm.

2. It is advisable to send the current in the circuit, only for the minimum time during which a null point is determined. Can you explain why ?

To make the bridge fairly sensitive an appreciable current is to be passed and hence the passage of this large current for a longer time will heat the apparatus, as a result of which the null point will change.

3. Would you take a long or short wire for connecting the two extreme ends of the resistances to the bridge ?

These connecting wires should be *just sufficiently long* to have the null points for the extreme ends of the two low resistances at the two ends of the bridge wire. If *very long* connecting wires are taken, then the null points for the extreme ends will be sufficiently shifted from the ends in which case l_1 and l_2 will be smaller, and percentage of accuracy will be less.

4. Would you prefer a storage cell or any other cell ?

For greater sensitiveness, a comparatively strong current is required and hence a storage cell with sufficient series resistance is perferable to a Leclanche's cell.

5. Will your result be affected by the non-uniformity of the bridge wire ?

Yes ; for we have deduced the formula on the assumption that the resistance is proportional to length, which will be true for a uniform wire only.

6. What is your idea regarding the equivalent resistance between the two terminals of the battery ?

The low resistance branch and the bridge wire are joined in parallel to the battery and hence the equivalent resistance will be even less than the lower of the two resistances in parallel.

7. Is it desirable to repeat the experiment by interchanging the two resistances in the two gaps ?

Yes, for if the wire of the metre bridge be non-uniform then the ratio X/R will be different when they are interchanged. Hence to avoid the error due to non-uniformity of the wire, resistances should interchange the gaps.

36. Galvanometer and their uses.

(a) Suspended magnet type.

All tangent and sine galvanometers belong to this category.

(i) Single coil tangent galvanometer.

Description : In a single coil tangent galvanometer [Fig. 63] two or more coils having different number of turns and each having separate binding screws are wound on a vertical circular metal frame capable of rotation about a vertical axis. When necessary, one or all the coils may be used. At the centre of the coil, a *short magnetic needle,* with an aluminium pointer, attached at right angles to the needle, is pivoted. The needle is also at the centre of a horizontal circular scale graduated in for quadrants from 0° to 90°. The ends of the pointer move over the circular scale. The magnetic needle and the pointer are enclosed in a glass case to protect them from wind disturbances.

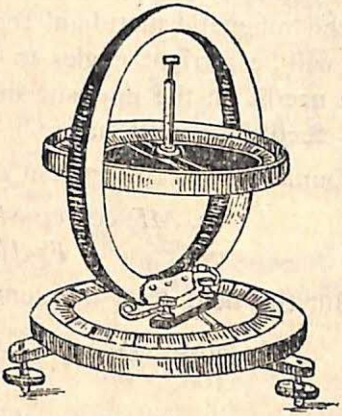

Fig. 63

Adjustments : (*i*) Levelling screws at the base are adjusted to make the rotation of the needle free and plane of the coil vertical.

(*ii*) The plane of the coil is rotated and brought to the magnetic meridian. At this time the magnetic needle will be contained in the plane of the coil and the pointer usually reads (0° – 0°) of the scale. If not, the box containing the circular scale should be rotated so that the pointer may read (0 – 0) when the plane of the coil contains the magnetic needle. The exact coincidence of the plane of the coil with magnetic meridian can be tested by sending direct and reversed currents through the galvanometer and rotating the scale, at the centre of which the needle is pivoted. If the pointer gives *equal deflections with direct and reversed currents,* then the coil is in the magnetic meridian.

Theory : If a current of C amperes be made to flow through the coil, the magnetic needle of moment M will be acted upon by two couples; one due to earth's horizontal field (H) and another due to the uniform magnetic field (F) of the circular current, produced over a very *small region* round the centre and at right angles to the plane of the coil. As the plane of the coil is in the magnetic meridian, the two uniform magnetic fields H and F will be at right angles to each other and will exert couples on the needle in the opposite directions. Hence for equilibrium of the needle we must have,

couple due to the current's field=couple due to earth's field

$$\text{or, } MF\cos\theta = MH\sin\theta,$$

$$\text{or, } \qquad F = H\tan\theta.$$

But the field F at the centre of the single coil is given by,

$F=\dfrac{2\pi nC}{10a}$; where, n=number of turns of the coil,

a=radius of the coil.

$$\therefore\ \frac{2\pi nC}{10a}=H\tan\theta\ ;\qquad \text{or,}\quad C=10\frac{aH}{2\pi n}\tan\theta=10K\tan\theta\ ;$$

where $K=\dfrac{aH}{2\pi n}$ =reduction factor of the tangent galvanometer. For a given value of C, θ will be large when K is small, *i.e.* when a is small and n is large.

The error in the measurement of current (C) would be minimum when the initial deflection is kept at 45°. The proportional error $\left(\dfrac{\delta C}{C}\right)$ in the measurement of C is given by,

$$\frac{\delta C}{C}=\frac{\delta(K\tan\theta)}{K\tan\theta}=\frac{\sec^2\theta\,\delta\theta}{\tan\theta}$$

$$\text{or, } \frac{\delta C}{C}=\frac{2\delta\theta}{\sin 2\theta} \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad (1)$$

It is evident from (1) that for a given error in measuring the angle of deflection by an amount $\delta\theta$, the proportional error in measuring C will be minimum when $\sin 2\theta$ is greatest, *i.e.* $\theta = 45°$.

(ii) Double coil or Helmholtz's tangent galvanometer.

Description : In Fig. 64, two identical coils having the same radii ($=a$) and the same number of turns (n) are wound on two circular frames whose centres are kept separated by a distance equal to the radius of either (a). The two coils are joined in series and their centres lie on a horizontal line. A short magnetic needle is pivoted at a point on the horizontal line joining the centres of the two coils and midway between them, so that the distance of the needle from the centre of each coil is $a/2$. A long aluminium pointer attached at right angles to the needle moves over a horizontal circular scale, the centre of which coincides with that of the needle. The two coils can be rotated as a whole about a vertical axis passing through the centre of the neddle.

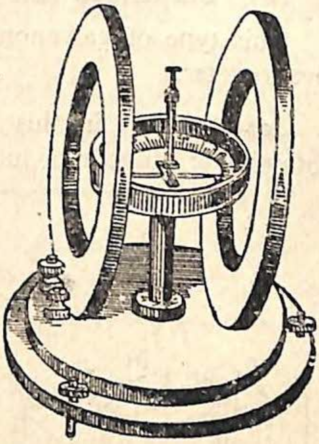

Fig. 64

Adjustments : Adjustments are the same as in the case of a single coil tangent galvanometer.

Theory : When the moments of the couple due to earth's field (H) and the couple due to the magnetic field (F) of the current in the two coils are equated, we get,

$$C = 10\frac{5\sqrt{5}aH}{32\pi n}\tan\theta = 10\frac{5\sqrt{5}}{16}\cdot\frac{aH}{2n\pi}\tan\theta = 10\frac{5\sqrt{5}}{16}K\tan\theta$$

or, $C = 10K'\tan\theta$; where $K' = \frac{5\sqrt{5}}{16}K$. Thus the reduction factor K' of a double coil tangent galvanometer is less than that ($=K$) of a single coil tangent galvanometer. Hence for a given value of C, the deflection θ would be large in the case of a double coil tangent galvanometer than in the case of a single coil tangent galvanometer. Thus this galvanometer is more sensitive than the single coil one. As the needle moves over an area having a more uniform field than in the case of a single coil galvanometer, the tangent law is fully obeyed in this case. So it is more accurate than the single coil tangent galvanometer.

(b) Suspended coil type.

This type of galvanometer is most sensitive than any other galvanometer.

Description : In this arrangement a rectangular frame (*C*) containing a number of turns of fine insulated coil of copper wire is kept suspended by fine phosphor-bronze strip (*P*) within the concave cylindrical pole pieces (*N* & *S*) of a permanent horse-shoe magnet [Fig. 65]. The coil (*C*) can rotate round a soft iron cylinder (*L*) which is placed in such a way that its axis coincides with the axis of the concave cylindrical pole pieces. One end of the coil is joined to one binding screw through the suspension wire while the lower end of the coil goes to the second binding screw though a phosphor-bronze spiral (*s*). The suspension wire and the phosphor-bronze spiral exert a controlling couple when the coil is deflected. A small plane mirror (*M*) is fixed to the suspension wire for recording the deflection of the coil by lamp and scale arrangement. The whole thing is enclosed in a case provided with three levelling screws. The case is provided with a glass window near the mirror *M*.

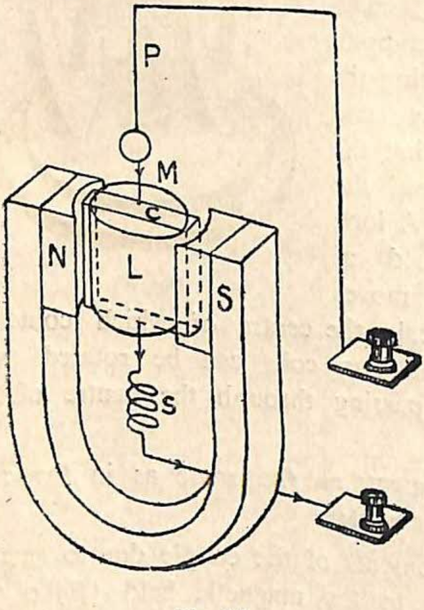

Fig. 65

Adjustments : (*i*) The levelling screws at the base of the case are adjusted until the coil is free to move [here spirit level is unnecessary for levelling purposes].

(*ii*) Light from a lamp is made converging by a converging lens and after reflection of these convergent rays from the mirror M, they are made to converge on a translucent scale placed at a distance of about one metre from the mirror M.

Theory : When a current of i e.m.u. flows through a coil of n number of turns wound on a rectangular frame of area A which is kept suspended in a radial magnetic field of strength H, the coil experiences a deflecting couple of magnitude $AnHi$ which is balanced by the controlling couple due to a twist of θ radian in the suspension wire. If c be the controlling couple for 1 radian twist in the suspension wire, then for equilibrium of the coil we must have,

deflecting couple=controlling couple

$$\text{or,}\quad AnHi=c\theta$$

$$\text{or,}\quad i=\frac{c}{AnH}\theta=k\theta.$$

For a given current i, θ will be large when $\frac{c}{AnH}$ is small. Thus by increasing the area A of the coil, the number of turns n of the coil, the radial magnetic field strength H of the horseshoe magnet and by decreasing the controlling couple c of the suspension wire, we can make the deflection θ large.

Sensitivity : The suspended coil galvanometer may have (1) *current sensitivity and* (2) *potential sensitivity.*

(1) The *current sensitivity* of the galvanometer is defined as the number of scale divisions deflections of the spot of light when a current of one micro-ampere passes through the galvanometer.

If $\delta\theta$ be the change of deflection caused by a small change of current by an amount δi then current sensitivity is given by,

$\frac{\delta\theta}{\delta i}$. Now the current i flowing through the galvanometer is given by,

$$i = \frac{c}{AnH}\theta.$$

$$\therefore \qquad \text{Current sensitivity} = \frac{\delta\theta}{\delta i} = \frac{AnH}{c}.$$

Thus the current sensitivity of the galvanometer can be increased by increasing the area (A) of the coil, the number of turns (n) of the coil, the strength of the radial magnetic field (H) and by diminishing the torsional couple (c) for 1 radian twist of the suspension wire.

As the coil has a large number of turns, its resistance must also be high. Thus a galvanometer having higher current sensitivity will also have higher resistance. This type of galvanometer is necessary where current measurement is to be made, as in the case of determination of the figure of merit of the galvanometer.

(2) The galvanometer will have *potential sensitivity* when a small change of potential difference will cause a large deflection. Thus if $\delta\theta$ be the change of deflection of the galvanometer coil, by a small change of potential difference δE at its terminals, then potential sensitivity is given by, $\frac{\delta\theta}{\delta E}$. This will increase when the galvanometer has low resistance.

For by Ohm's law ($C=E/R$), we see that a small change of E will cause a large change of C provided R is small. The galvanometer having high potential sensitivity is very useful in null point determinations. The resistance of such galvanometers should be below 50 ohms.

Dead-beat and ballistic pattern : In a dead-beat glvanometer, the oscillations of the coil, after the withdrawal of current, stop quickly due to the generation of induced current in the conducting copper frame of the coil which oscillates in the magnetic field of the horse-shoe magnet. Thus for electromagnetic damping of the coil, the frame on which the coil is wound should be made of a conducting material such as copper.

In ordinary work, the oscillating coil should come to rest quickly and hence this type of galvanometer is useful.

If the galvanometer is to be employed for ballistic purposes, then all sorts of damping in the coil should be avoided. For in this case, we require not the steady deflection of the coil but only the *first throw* of the coil, which will be reduced if the damping be present. The electro-magnetic damping as reduced by winding the coil on a non-conducting frame, such as bamboo frame, and the damping due to air resistance is eliminated by observing several successive amplitudes of oscillation of the coil. The period of oscillation of the coil should also be large.

37. Precautions to be taken in using a suspended coil galvanometer.

(*i*) The levelling screws at the base of the galvanometer case must be adjusted until the coil swings freely within the annular air gap between the soft iron cylinder and the concave cylindrical pole-pieces without touching any one of them. Here spirit level is unnecessary for the purpose of levelling.

(*ii*) The lamp position should be so adjusted that the light reflected from the mirror is focussed at the centre of the scale and strikes it almost *normally*. For this purpose, the torsion head may be twisted. The spot of light should be sharply focussed on the scale, and a *sharp edge of this spot of light should be made coincident with the zero mark* of the scale. When the spot of light is deflected, the reading corresponding to this sharp edge of the spot should be taken.

(*iii*) A *battery should in no case be directly connected with the galvanometer*, for in that case the galvanometer coil and the suspension wire may burn due to the generation of much heat by the flow of heavy current.

(*iv*) A high resistance should be connected in series with the galvanometer and a shunt box should be joined in parallel to it. The resistance in the shunt box should be *increased gradually from zero value* until the desired deflection is obtained.

(*v*) In the case of a dead-beat galvanometer, a short-circuiting key is unnecessary, for the oscillation of the coil in the magnetic field will be quickly checked by the generation of eddy current in the conducting frame, on which the coil is wound.

If the coil is wound on a non-conducting frame then it will oscillate for a long time before it comes to rest. To stop this oscillation quickly, a tapping key or a plug key (known as short-circuiting key) should be joined in parallel to the galvanometer. When the *spot of light is passing through its rest position,* the key should be suddenly closed to bring the spot to rest by the effect of eddy current generated in the coil itself by its movement in the magnetic field of the magnet.

(*vi*) Due to the production of a small thermo-current in the circuit, the *mean of the galvanometer deflections for direct and reversed currents should be found out* and for this purpose a commutator should be employed.

(*vii*) The deflection of the spot of light should be *maintained between* 8 *to* 16 *cms.* of the scale, otherwise current will not be proportional to the deflection.

(*viii*) Different types of galvanometer are desirable for different types of experiment. For *null point work* and for the measurement of relatively large current, low resistance galvanometer should be employed. Galvanometer resistance should not exceed 50 ohms.

For the measurement of a *very small current* and a relatively large potential difference a high resistance galvanometer (having a current sensibility) is desirable.

For the measurement of *quantity of charge,* a ballistic galvanometer (*i.e.* a galvanometer in which the coil has greater time-period of oscillation and that coil is wound on a non-conducting frame) should be employed.

38. Determination of the reduction factor of a tangent galvanometer (either single coil or double coil).

Connection of the apparatus : Connections are shown in Fig. 66. A copper voltameter V, a battery (B) (containing

3 or 4 alkali storage cells in series) and a rheostat (*Rh*) are all joined in series and connected to the two middle binding screws (C_5, C_6) of a Pohl's commutator. Care should be taken *to connect the negative of the cell with the cathode* **C** *of the copper voltameter.* A tangent galvanometer *G* (either single coil or double coil Helmholtz pattern) is joined with ose pair of binding screws (C_1, C_2) remaining on one side of the middle binding screws.

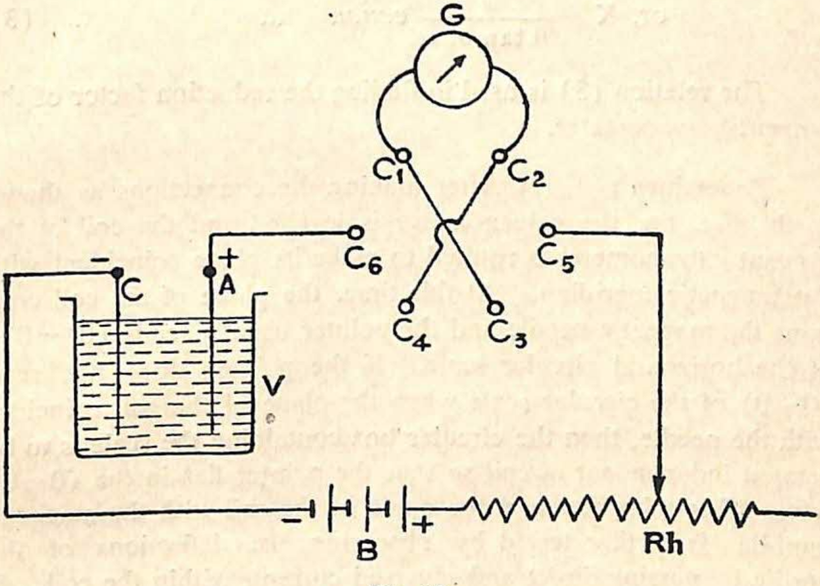

Fig. 66

Theory : If a current of *c* amperes be made to flow for *t* seconds through a *properly adjusted* tangent galvanometer, joined in series with a copper voltameter, then this current will produce a deflection θ of the tangent galvanometer needle and will also cause a deposition of *w* gms. of copper on the cathode of the copper voltameter. Hence we have for the tangent galvanometer.

$$c = 10K \tan\theta \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where K is the reduction factor of the galvanometer. Again, for a copper voltameter,

$$w = zct\,; \qquad \text{or, } c = \frac{w}{zt} \quad \dots \quad \dots \quad (2)$$

where z is the Electro-chemical equivalent of copper in gms. per coulomb.

$$\text{From (1) and (2) we get, } 10K \tan\theta = \frac{w}{zt}$$

$$\text{or, } K = \frac{w}{10 \tan\theta .\, zt} \text{ e.m.u.} \quad \dots \quad \dots \quad (3)$$

The relation (3) is used in finding the reduction factor of the tangent galvanometer.

Procedure : (*i*) After making the connections as shown in the Fig. 66, the galvanometer is levelled and the coil of the tangent galvanometer is rotated to make its plane coincident with the magnetic meridian. At this time, the plane of the coil contains the magnetic needle and the pointer usually reads (0° – 0°) of the horizontal circular scale. If the pointer does not read (0 – 0) of the circular scale when the plane of the coil coincides with the needle, then the circular box containing the scale is to be rotated independent of coil so that the pointer lies in the (0 – 0) line. This coincidence of the plane of the coil with the magnetic meridian is further tested by observing the deflections of the needle by passing direct and reversed currents within the coil. If the two deflections with direct and reversed currents are equal then the plane of the coil coincides with the magnetic meridian.

(*ii*) The rheostat is then adjusted to pass a suitable current through the galvanometer, until the deflection is 45° (both for direct and reversed currents). The current is then made off and the cathode of the copper voltameter is taken out and placed on a piece of clean paper. Both surfaces of the cathode plate are now rubbed by a *fine grained* sand paper to make the surfaces perfectly clean and free from grease. When both the surfaces are very clean, fine particles on the plate are brushed off by a clean cotton. The plate is washed in a jet of distilled water from a wash bottle and *dried thoroughly* by holding it under a fan. Now the plate-surfaces should no longer be touched by hand, nor the plate should be kept on a dirty table.

(*iii*) The plate is now carefully weighed in a balance. This weighing is to be done very accurately by using a rider. After weighing the plate, it is replaced in the position of the cathode and both the current and a stop-clock are started simultaneously. When the position of the needle is steady, the reading for the two ends of the pointer are noted.

(*iv*) The current is allowed to flow for half an hour and during this period, the direction of the current in the galvanometer is reversed after each five minutes' interval. The mean of these deflections is found out.

(*v*) The cathode plate is now withdrawn and washed in a stream of tap water and then with distilled water and dried under a fan. When the plate is *perfectly dried,* it is weighed again in a balance by using a rider. The difference between the second and the first weights of cathode gives the mass w of copper deposited on it. Time t of the flow of current, is known from the stop-clock and z the *E. C. E.* of copper is given. Hence we can find K from the relation (3).

Experimental data :

(A). *To find the mass of copper deposited* :—

TABLE I

Mass of cathode plate,		Mass of copper deposited $w=(w_2-w_1)$
Before deposition (w_1)	After deposition (w_2)	
.. *gm*+...*gm* +...*mg*+.. *mg*+... =...*gm*	.. *gm*+...*gm*+... *mg*+...*mg*+... =....*gm*	(...)*gms*

(B). *Time—Deflection record.*

TABLE II

Time interval in minutes.	Nature of current.	Deflection in degrees.		Mean deflection in degrees. θ
		End I	End II	
$0-5$	Direct	45	46	...
$5-10$	Reversed	...	...	
$10-15$	Direct	...	...	
$15-20$	Reversed	...	...	
$20-25$	Direct	...	...	
$25-30$	Reversed	...	...	

Calculation :

z=E.C.E. of copper (given)=·0003293 gms/coulomb.

$$\therefore \quad K=\frac{w}{10\tan\theta.\,zt}= \quad \ldots \quad = \quad \ldots \quad \text{e.m.u.}$$

Precautions : (*i*) The instrument is to be levelled to make the *plane of the coil vertical* and the needle free to rotate.

(*ii*) Deflections of the needle *both for direct and reversed currents should be made equal* to ensure the coincidence of the plane of the coil with the magnetic meridian.

(*iii*) The strength of the current should be such, as not to exceed 1 ampere for each 50 sq. cm. area of the immersed cathode.

(*iv*) Cathode plate should be weighed after it is made *perfectly dry,* otherwise much error will be introduced in the value of *K* due to the increase in weight of cathode on account of moisture present on it. The cathode must be *clean and free from grease.*

(*v*) The copper sulphate solution should be *freshly prepared* having a density of about 1·16. For good deposition and for avoiding oxidation of anode, 1 c.c. of strong sulphuric acid and 1 c.c. of ethyl alcohol should be added for each 100 c. solution.

(*vi*) The deflection is to be kept at 45° for minimum propo tional error in the measurement of current.

Oral Questions and their Answers

1. What is a tangent galvanometer and how does it differ from suspended coil galvanometer ?

A galvanometer in which the current is proportional to the tangen of the angle of deflection of the needle is called a tangent galvano meter.

In a tangent galvanometer a magnetic needle in placed in two uniform crossed magnetic fields, one due to the earth's horizontal field (*H* while another is due to the uniform field (*F*) at the centre of the circula current. In suspended coil galvanometer a rectangular coil carrying current is suspended in the radial field of a horse-shoe (permanent magnet whose pole pieces are made concave cylindrical. This galvano meter is more sensitive than the tangent galvanometer.

2. Why (*a*) the plane of the coil is brought to the magnetic meridia and kept vertical (*b*) the magnetic needle is made short ?

(*a*) As the field due to the circular current is perpendicular to th plane of the coil, the crossed condition of the two uniform fields *H* an *F* will be obtained when the plane of the coil is kept along the magneti meridian. The plane of the coil is kept vertical so that the magneti needle, free to rotate in the horizontal plane, may be affected by th full values of *F* and *H* and not by their components. (*b*) The magneti field *F* due to circular current is uniform over a small region round th centre and hence the needle is made short so that it can move in tha uniform field.

3. Define the reduction factor of a galvanometer. Is its value con tant at all places ?

The reduction factor $K\left(=\frac{aH}{2\pi n}\right)$ is a factor which when multiplie with $\tan\theta$ we get current. This reduction factor depends on th earth's horizontal field (H), radius of the coil (a) and the number turns of the coil (n). No, the value of K is different at differe places on the earth's surface due to the different values of H at tho places.

4. How many types of tangent galvanometer are there and whi is more sensitive and accurate ?

A Double coil tangent galvanometer (Helmholtz's galvanometer) is more sensitive and accurate than the single coil one.

[For details, see the theories of a single and a double coil tangent galvanometer Art. 36].

5. How does the deposition of copper on the cathode occur? Does the strength of the solution decrease by such deposition? Is the gain in weight of the cathode equal to the loss in weight of the anode?

Within $CuSO_4$ solution there are Cu^{++} and SO_4^{--} ions. By the passage of current, Cu^{++} is deposited on the cathode while SO_4^{--} attacks the copper of the anode forming $CuSO_4$ back and maintains the strength of the solution constant. Thus pure copper from the anode will be transferred to the cathode while the impurities on the anode will fall down. Hence the loss in weight of the anode cannot be equal to the gain in weight of the cathode.

6. What strength of the current you should pass through the circuit?

For each 50 sq. cm. area of the immersed cathode the current should be one ampere. A very feeble current will take a long time for an appreciable deposition while a very strong current makes the deposition loose, which goes away during washing. Hence the current should be of the above order.

7. What will happen if the current is reversed in the voltameter also along with the galvanometer current.

Anode and cathode will change by such reversing and consequently there will be no deposition on any plate.

8. Do you require a storage battery or a Leclanche's cell?

We require a constant current to keep the deflection at 45° and this can be obtained with a storage battery only and not from Leclanche's cell due to its partial polarisation.

9. A given current can be passed in the circuit with high E.M.F. and a high rheostat resistance and also with a low E.M.F. and a low series resistance. Which one would you prefer?

The former one; for if the resistance present in the circuit be initially high, then a small change of circuit-resistance cannot disturb the original current.

10. Why do you keep the deflection of the galvanometer at 45°?

The proportional error in the measurement of current would be minimum if the deflection is kept at 45°.

11. Why do you take the readings for both ends of the pointer and also with direct and reversed currents?

To avoid eccentric error (error arising out of the non-coincidence of the centre of the needle with the centre of the circular scale), the readings of the two ends of the pointer are noted. To eliminate the error arising out of the non-coincidence of the plane of the coil with the magnetic meridian, readings are taken both for direct and reversed currents.

12. What will happen if platinum electrodes are taken instead of copper electrodes ?

In that case deposition of copper on the cathode will occur from the solution whose strength will decrease with time.

39. Determination of Electro-chemical equivalent of copper by using an accurate ammeter and copper voltameter.

Apparatus : The apparatus required for this experiment are, (*i*) 3 or 4 alkali storage cells in series (*B*), (*ii*) an accurate ammeter (*M*), (*iii*) a variable resistance (*Rh*), (*iv*) a plug key (*K*) and (*v*) a copper voltameter (*V*), which is a glass vessel containing copper sulphate solution in which two anode plates (*A*, *A*) and a cathode plate (*C*) are partially immersed.

Connections of the Apparatus : Connections are shown in Fig. 67 in which the battery (*B*), the ammeter (*M*), the rheostat (*Rh*), the key (*K*) and voltameter (*V*) are all placed in series. The −*ve* of the battery is joined to the cathode plate *C* while the wire from the key *K* joins the two anodes which are beforehand joined externally by a wire.

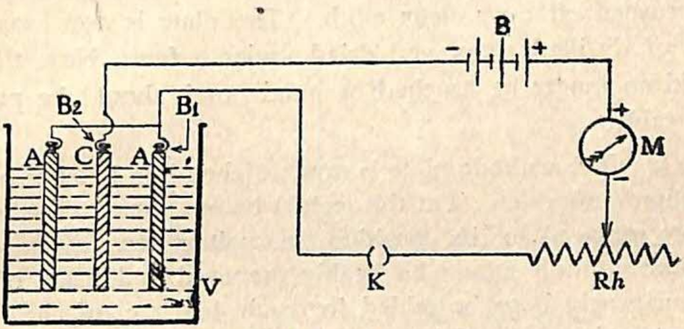

Fig. 67

Theory : If a current of *c* amperes, as indicated by an accurate ammeter, be allowed to flow through a copper voltameter in which *w* gms. of copper are deposited on the cathode of the voltameter in *t* seconds then according to Faraday's first law of electrolysis, we get,

$$w=zct\,; \quad \text{or, } z=w/ct. \qquad \dots \quad \dots \quad \dots \quad (1)$$

where z is the electro-chemical equivalent (*E.C.E.*) of copper, i.e. the mass of copper deposited on cathode by the flow of 1 coulomb of electricity. Knowing w, c and t we can find z.

Procedure : (*i*) The length (l) and breadth (b) of the area of the cathode plate C, to be introduced into the copper sulphate solution, are to be first measured by a scale. Hence the total area of immersed cathode would be $2lb$.

(*ii*) The cathode (without cleaning) is introduced into the voltameter and the circuit is made as shown in Fig. 67. On closing the circuit, the rheostat resistance is adjusted until the current in the circuit, as indicated by the ammeter M, remains slightly below one ampere for each 50 sq. cm. of the immersed area of cathode. After this adjustment of current, the key K is made open to break the circuit.

(*iii*) The cathode C is now taken out and both of its surfaces are cleaned by a fine grained sand paper. When both the surfaces of cathode are cleaned, fine particles of sand on cathode are brushed off by a clean cloth. The plate is now washed by a jet of distilled water and dried under a fan. Now the plate should no longer be touched by hand nor it should be put on a dirty table.

(*iv*) The cathode plate is now weighed in a balance by using a centigramme rider. Let this weight be w_1 gms. The cathode is now replaced in its position in voltameter. [The copper sulphate solution should be freshly prepared and 1 c.c. of strong sulphuric acid is to be added for each 100 c.c. of the solution to increase its conductivity. Again to prevent oxidation of anode, 1 c.c. of ethyl alcohol is to be added for each 100 cc. of the solution.]

(*v*) The key K is now closed and current is passed for 30 minutes (t) which is noted by a stop-clock. During this 30 minutes, the readings of the ammeter are to be noted after five minutes interval. The mean ammeter reading (c) is then to be found out.

(*vi*) The circuit is broken after 30 minutes and the cathode plate C is taken out. The plate is now washed in a stream of tap water and then finally by distilled water. The plate is again dried under a fan and its weight w_2 is determined very accurately. The mass of copper deposited on cathode in time t (=30 minutes) is $w=(w_2-w_1)$ gms. Knowing w, c and t, the value of z can be calculated by using the relation (1).

Experimental data :

(A). *To find the mass of copper deposited :—*

TABLE I

[Make a table as given in item (*A*) of Expt. 38, Part II]

(B). *Data for finding E.C.E. of copper :—*

TABLE II

Time of flow of current$=t=30\times60=1800$ seconds

Time interval in mins.	Ammeter reading	Mean ammeter reading (C)	Mass of copper deposited in gms. (w) (From table I)	*E.C.E.* of copper $=z=w/ct$ gms./coulomb
0–5	....	...	...	...
5–10	...			
10–15	...			
15–20	...			
20–25	...			
25–30	...			

Calculation :

$z=w/ct$ = ... = ... gms. per coulomb.

Oral Questions and their Answers

1 to 5. [See the answers of questions 5 to 9 at the end of Expt. 38]

6. What do you mean by the term electro-chemical equivalent of a substance ? E.C.E. of a substance is the amount of it liberated at an electrode by the passage of 1 coulomb of electricity through a solution of the substance.

7. What law is employed to find E.C.E. of the substance ? Faraday's first law of electrolysis is employed to find E.C.E. of the substance. The law states that the amount of substance (w) liberated at an electrode is proportional to the quantity of electricity ($q=ct$) passing through a solution of the substance.

8. Can you employ alternating current to find z ? No ; for anode and cathode will change continuously, as a result no deposition will take place.

9. How would you find z when no ammeter is supplied ? If no ammeter is supplied to measure the current c in the circuit, then a low resistance r (say, $r=\cdot 1$ ohm) is to be inserted in the circuit in place of ammeter. By using a potentiomoter, the P.D. e existing at the ends of this low resistance is to be measured. Hence the current in the voltameter circuit would be $c=e/r$.

40. Verification of Ohm's law by using a tangent galvanometer.

Apparatus : The apparatus required are,—(1) a tangent galvanometer (either a single coil or double coil), (2) two storage cells in series, (3) a resistance box and (4) a commutator (either plug commutator or Pohl's commutator).

Connections of the Apparatus : The battery *B′* (containing two alkali cells in series) and the resistance box *R* (in which a total resistance of about 1000 ohms should be available) are joined in series with the tangent galvanometer G through a commutator *K* [Figs. 68(*a*) and 68(*b*)]. In Fig. 68(*a*), connections with plug commutator is shown, in which the battery *B′* and the resistance box *R* are connected to one diagonal *AB* while the galvanometer *G* is connected to another diagonal *FD*. In Fig. 68(*b*), connections with Pohl's commutator are shown.

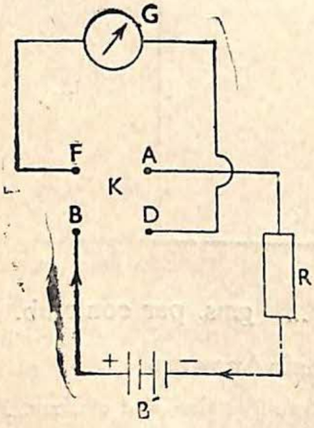

Fig. 68(*a*)

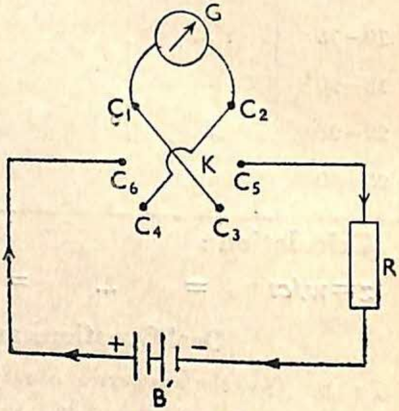

Fig. 68(*b*)

Theory : Ohm's law states that the current (*C*) flowing through a conductor at uniform temperature, is directly proportional to the potential difference (E) at the ends of the conductor. Hence $C \propto E$ when temperature is constant,

or, $E=CR$ ... ... (1)

here R is a constant which depends on the dimension, nature and temperature of the conductor and is known as the resistance of the conductor.

If a current of C amperes flows through a tangent galvanometer of resistance G ohms and reduction factor K, and also through a resistance R ohms (inserted in the box) then by Ohm's law,

$$C=\frac{E}{R+G+r} \qquad \ldots \qquad \ldots \qquad \ldots \qquad (2)$$

where E is the $E.M.F.$ of the battery and r is the total resistance of the battery and the connecting wires. If θ be the deflection of the galvanometer needle then,

$$C=10\ K \tan\theta \qquad \ldots \qquad \ldots \qquad \ldots \qquad (3)$$

From (2) and (3) we get,

$$10\ K \tan\theta=\frac{E}{R+G+r};$$

or,
$$\cot\theta=\frac{10K}{E}(R+G+r)=\text{const.}\ (R+G+r) \ \ldots\ldots \quad (4)$$

Also,
$$(R+G+r)\tan\theta=\frac{E}{10K}=\text{constant} \qquad \ldots \qquad \ldots \qquad (5)$$

Either relation (4) or the relation (5) or both the relations (4) and (5) may be employed to verify Ohm's law.

If a graph be drawn with the various values of R (inserted in the box) along x-axis and the corresponding values of $\cot\theta$ along y-axis [taking $(0-0)$ as the origin] then it is evident from the eqn. (4) that the graph should be a straight line having an intercept on the x-axis equal to $(G+r)$ or practically equal to G, for r is negligibly small [Fig. 69]. If by experiment, the graph between R and $\cot\theta$ is found to be a straight

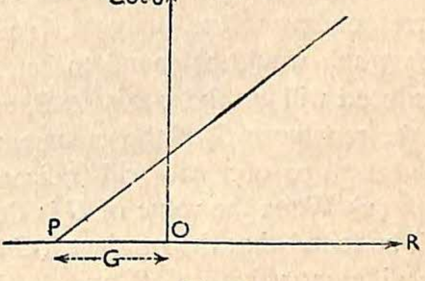

Fig. 69

line then Ohm's law will be verified. Ohm's law can also be proved to be true, by showing the product $(R+G) \times \tan\theta$, constant; for r is negligibly small in comparison with $(R+G)$.

Procedure : (*i*) The galvanometer is levelled by a spirit level so that the needle and the pointer may swing freely and the plane of the coil may be vertical. The plane of the coil is rotated, until it contains the magnetic needle. At this time, the pointer attached to the needle should read $(0-0)$ of the scale. If this does not occur, then the box containing the circular scale is to be rotated a little to make the pointer read $(0-0)$ of the scale. This time the plane of the coil is in the magnetic meridian. The exact coincidence of the plane of the coil with the magnetic meridian is made by sending a direct and reversed current within the coil and making the two deflections with these two currents equal by slightly rotating the circular scale.

(*ii*) A large resistance is now inserted in the box when a small deflection of the pointer will be observed. The resistance in the box (R) is decreased until the deflection of the pointer is $30°$. The readings of the scale for the two ends of the pointer are noted. The current in the galvanometer is then reversed by the commutator and again the readings of the scale for the two ends of the pointer are noted. The mean of these four deflections gives the exact value of θ, for the given resistance in the box.

(*iii*) The operation (*ii*) is repeated with gradually decreasing resistance in the box, to increase the deflection of the pointer by steps of $5°$ until the final deflection is $60°$.

(*iv*) From the trigonometrical table, the values of $\cot\theta$ or the values of $\tan(90-\theta)$ are determined. A graph is then drawn with the different values of R along x-axis while the corresponding values of $\cot\theta$ [or $\tan(90-\theta)$] along y-axis. The graph would be found to be a straight line, which when produced will cut the x-axis at P, so that the value of OP will be the resistance G of the galvanometer (Fig. 69). This straight-line graph so obtained will indicate the truth of Ohm's law.

(*v*) When the value of G is thus obtained from the graph, it will be found that the product, $(G+R)\times\tan\theta$ is always constant for different values of R and θ. This also verifies Ohm's law.

Experimental data :

(A). *$(R-\theta)$ records* :—

Galvanometer resistance from graph$=G=$ ... Ohms.

No. of obs.	Res. in ohms from the box (R)	Galv. deflections in degrees with				Mean of 4 deflections in degrees (θ)	cot θ	tan θ	$(R+G)\times(\tan\theta)$	Conclusion
		Direct current		Reversed current						
		End I	End II	End I	End II					
1	...	30	...	...	....	....	...	...	....	The st. line nature of $(R-\cot\theta)$ graph and constant value of $(R+G)\tan\theta$ verify Ohm's law.
2	...	35	....	...	....	...	...	...	...	
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc	
6	...	...	...	...	...	...	....	...	...	
7	...	...	...	...	....	...	...	...	...	

(B) *Drawing of $(R-\cot\theta)$ graph* :—

The various values of R should be plotted along x-axis, while the corresponding values of cot θ should be plotted along y-axis by taking the origin as (0—0). A best straight line is to be drawn by joining the points. The straight line should be produced to cut the x-axis. The value of the intercept on the x-axis will give the resistance G of the tangent galvanometer. For when, $y=\cot\theta=0$; $G+r=-R$; *i.e.* $G=R$ numerically for r is practically zero.

[For details of drawing the graph, see Art. 5. Part I.]

Precautions : (*i*) The connecting wires employed should be short so that their total resistance may be negligibly small. (*ii*) For minimum proportional error, the deflections should lie near about 45°.

(*iii*) All magnets and magnetic substances should be removed from the working table during experiment.

Oral Questions and their Answers

1—4. [Same as those in the Expt. 38]

5—6. [Same as those of Q. 10 and Q. 11 of Expt. 38]

7. State Ohm's law and explain how does it provide the definition of resistance [see the 1st paragraph of theory].

8, What is conductance and conductivity of a conductor ?

The reciprocal of the resistance of a conductor is called its conductance while the reciprocal of the resistivity or specific resistance of the material of the conductor will be known as the conductivity of the material.

9. What is supra-conductivity ?

When the temperature of a conductor is very near to 0°*K* the resistances of some metals suddenly begin to diminish at a much rapid rate and tend to vanish at 0°*K*. This phenomenon is called supra-conductivity and the substances are then said to be in the supra-conducting state.

10. Is Ohm's law valid for conduction in gases ?

If gases are made conducting by some ionising agents, then this ionised gas obeys Ohm's law within a small range of potential difference, but when the potential difference is very high, the current attains its saturation value.

41. Determination of the resistance of a mirror galvanometer by half deflection method.

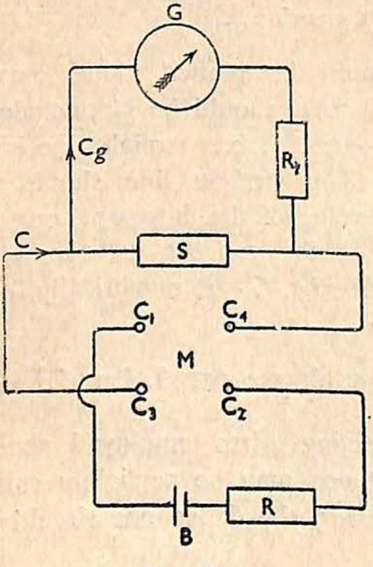

Fig. 70

Connections of the apparatus : Connections are shown in Fig. 70, in which a storage battery *B* (usually one or two alkali cells in series), a resistance box *R* (in which high resistance is inserted) are connected in series to the two diagonally opposite binding screws C_1 and C_2 of a plug type commutator *M*. The other two diagonally opposite binding screws C_3 and C_4 of commutator *M* are joined to the shunt box *S*. The mirror galvanometer *G* and a resistance box R_1 (the total resistance in R_1 must be greater than the expected galvanometer resistance G) are joined in series and the two together are connected parallel to the shunt box S (in which ·1 ohm should be applied).

Theory : If the shunt resistance S is very low in comparison with the galvanometer resistance G, then the potential difference (V) across the shunt resistance S is independent of the resistances in the galvanometer circuit.*

Let d and $d/2$ be the deflections of the spot of light on the scale, when the resistance in the box R_1 of the galvanometer circuit are successively zero and R_1. If C_g and C'_g be the galvanometer currents in the two cases, then we may write,

$$C_g = \frac{V}{G} = kd \quad \text{.....} \quad \text{.....} \quad \text{.....} \quad (1)$$

$$C'_g = \frac{V}{G+R_1} = \frac{kd}{2} \quad \text{.....} \quad \text{.....} \quad \text{.....} \quad (2)$$

where k is a constant.

Taking the ratio of (1) and (2) we get,

$$\frac{G+R_1}{G} = 2\ ; \qquad \text{or,}\quad 1+\frac{R_1}{G} = 2\ ;$$

or, $G = R_1$.

Procedure : (i) One sharp edge of the spot of light is brought at the zero mark of the scale and then the connections are made as shown in Fig. 70 with the shunt resistance as ·1 ohm. Keeping the resistance in the box R_1 of the galvanometer circuit equal to zero, the resistance R in the battery circuit is decreased from a high value until the deflection of the spot of light on the scale lies between 8 to 16 cm. This

---

* The equivalent resistance of S and $(G+R_1)$, which are joined in parallel, is given by $\frac{S(G+R_1)}{G+R_1+S}$. If C be the main current then the potential difference (V) across the shunt resistance S is given by,

$$V = C\frac{S(G+R_1)}{G+R_1+S} = \frac{CS}{1+\frac{S}{G+R_1}}.$$

When S is very small in comparison with $(G+R_1)$, we may neglect the ratio, $\frac{S}{G+R_1}$. Hence, $V=CS$, which is independent of the resistances in the galvanometer circuit.

deflection is noted. Now keeping this value of R constant, the value of the resistance in the box R_1 is increased from zero value until the deflection is reduced exactly to *half of the former*. This value of R_1 is then the resistance of the galvanometer.

(*ii*) The current is now made off in the circuit and examined whether the same sharp edge of spot of light, still remains at zero. If not, it should be brought to zero, by adjusting the scale. The value of R_1 is now made zero and the value of R is kept the same as before.

The direction of the current in the circuit is then reversed by the commutator M. The deflection is noted and a suitable value of R_1 is inserted to make this deflection again exactly half of that when R_1 was zero. This value of R_1 gives the galvanometer resistance with the reversed current.

(*iii*) Operations (*i*) and (*ii*) are repeated for three or four different values of R in the battery circuit and three or four different values of shunt resistance S, but maintaining the deflections in each case within the range of 8 to 16 cms. Thus for each value of R we get two values of galvanometer resistance G (one for direct and another for reversed current). Hence for three or four different values of R and S we get six or eight values of G, the mean of which gives the galvanometer resistance.

Precautions : (*i*) The shunt resistance must be *very low* otherwise the assumption made in the theory will not be justified.

(*ii*) The cell employed must be a *storage cell* otherwise deflections will not remain steady.

(*iii*) When the operation with the reversed current is to be performed, care is to be taken to bring the spot of light at the zero of the scale.

(*iv*) The assumption that the current would be halved when the deflection is reduced to half will not be justified unless the deflection is *small* (say between 8 to 16 cm.).

Experimental data :

E.M.F. of the storage battery employed=

.....volts [Before Expt.]
..... " [After "]

No. of obs.	Currents	Res. in the battery circuit (R) in ohms.	Shunt resistance (S) in ohms.	Res. in the galvanometer circuit (R_1) in ohms	Galvanometer deflections in cm.	Galv. Resistance (G) in ohms.	Mean G in ohms
1.	Direct	460	·1	0	8·4		
		,,	,,	172	4·2	172	
	Reversed	,,	,,	0	8·6		
		,,	,,	174	4·3	174	
2.	Direct	...	...	0	...		
		,,	,,	...	...	....	
	Reversed	,,	,,	0	....		
		,,	,,	...	...	....	...
3.	Direct	...	...	0			
		,,	,,	..	...	...	
	Reversed	,,	,,	0	...		
		,,	,,	...	...	...	
4.	Direct	...	...	0	....		
		,,	,,	...	....	....	
	Reversed	,,	,,	0	....		
		,,	,,	....	...	...	

Oral Questions and their Answers

1. What do you mean by the term 'galvanometer resistance' ?

By the term 'resistance of the galvanometer' we mean the resistance of the coil of wire wound over the rectangular frame which is kept suspended.

2. Why do you maintain the deflection between 8 to 16 cms. ?

If the galvanometer is not provided with concave cylindrical pole-pieces, the current is not proportional to the deflection and hence the displacement of the spot of light was kept small, say between 8 to 16 cms. Again even when the pole-pieces are made concave, the current is proportional to the angle of rotation θ of coil in radain which will be approximately equal to tan θ when θ is not large. That is, current will be proportional to the displacement of the spot of light when θ is not large.

3. When does this method fail ?

This method will give satisfactory value only when the resistance of the galvanometer is very high in comparison with the shunt resistance. Hence the method fails for a very low resistance galvanometer. When the resistance of the galvanometer is low, it is best measured by clamping the coil and measuring the resistance of the coil in the usual way by employing a metre bridge or a P. O. box.

4. Can this method be applied to measure the resistance of a tangent galvanometer ?

No ; for here the current is not proportional to the deflection and the pointer method of noting deflection makes it so much insensitive that by shunting the galvanometer we shall get practically very little deflection.

5. By applying a shunt resistance of about ·1 ohm what will be the resistance of a shunted galvanometer ?—Even less than ·1 ohm.

6. Do you prefer a high or low resistance of the shunt ?

Very low resistance of the shunt is preferred : for the theory of the experiment shows that the method will give fairly correct value of the galvanometer resistance when the shunt resistance is *very low*.

42. Determination of the Figure of merit (or, current sensibility) of a given mirror galvanometer.

Connections of the Apparatus : Connections are shown in Fig. 71, in which a storage battery *B* (usually one or two alkali cells in series), a resistance box *R* in which a high resistance is inserted are connected in series to the two diagonally opposite binding screws C_1 and C_2 of a plug type commutator *M*. The other two diagonally opposite binding screws C_3 and C_4 of commutator *M* are joined to the shunt box *S* containing

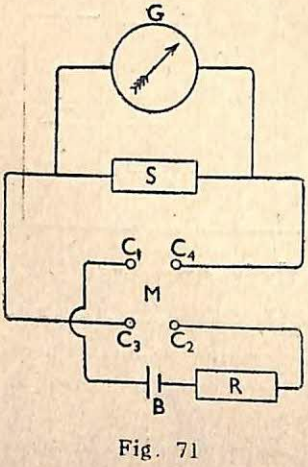

Fig. 71

fractional ohms. The galvanometer G whose figure of merit or current sensibility is required is joined in parallel to the shunt box S.

Theory : In Fig. 71, the resistance of shunted galvanometer is given by, $SG/(S+G)$. Hence the current flowing through the galvanometer is C_g = main current $\times \dfrac{S}{S+G}$.

$$\text{or,}\quad C_g=\frac{E}{R+SG/(S+G)}\times\frac{S}{S+G}=\frac{ES}{R(S+G)+SG}\qquad\cdots\quad(1)$$

If this current (C_g) produces a deflection of the light-spot by d cm. on a scale placed at a distance of D cm. from the galvanometer mirror, then the deflection which will be produced when the scale is at a distance of 100 cm. from the mirror is,

$$s=\frac{100d}{D}\text{ cm.}=\frac{1000d}{D}\text{mm.}\qquad\cdots\qquad\cdots\quad(2)$$

(*i*) *Figure of merit* (m) of a mirror galvanometer is defined as the current in amperes (or, in micro-amperes) required to produce a deflection of the spot of the light by *one mm.* on a scale placed normal to the beam of light at a distance of one metre from the galvanometer mirror. Hence,

$$\text{Figure of merit}=m=C_g/s=\frac{DC_g}{1000d}\text{amp./mm.}$$

$$\text{or,}\quad m=\frac{D}{1000d}\times\frac{ES}{R(S+G)+SG}\quad\text{amp./mm.}\qquad\cdots\cdots\quad(3)$$

$$\text{or,}\quad m'=\frac{D}{1000d}\times\frac{ES\times10^6.}{R(S+G)+SG}\text{ micro-amp./mm.}\qquad\cdots\cdots\quad(4)$$

(*ii*) *Current sensibility* (θ) of a mirror galvanometer is the number of *mm.* deflection of the spot of light on a scale placed, normal to the beam of light, at a distance of one metre from the galvanometer mirror when a current of one micro-ampere flows through the galvanometer.

Now, C_g amp. $= C_g \times 10^6$ micro-amps.

$$\textit{Current sensibility} = \theta = \frac{s}{C_g \times 10^6}$$

$$\text{or, } \theta = \frac{1000d}{D} \times \frac{R(S+G)+SG}{ES \times 10^6} \text{ mm./m.A.} \quad \ldots\ldots \quad (5)$$

It is evident from (4) and (5) that. $\theta = 1/m'$.

Procedure : (*i*) Connections of the circuit are made as shown in the Fig. 71. The spot of light is sharply focussed on the scale and its one sharp edge is brought in coincidence with the zero mark of the scale.

(*ii*) The distance (D) between the galvanometer mirror and the scale is measured by employing a metre scale. The *E.M.F.* (E) of the battery is found out by a voltmeter. The given resistance (G) of the galvanometer is noted.

(*iii*) At first the shunt resistance (S) is made zero and a suitable series high resistance (R) [say 4000 ohms] is applied in the circuit. The value of the shunt resistance (S) is then gradually increased (by steps of ·2 ohms) from this zero value until the deflection lies between 8 to 16 cm. of the scale. If the total shunt resistance is less than 1 ohm then both the series high resistance (R) and the shunt resistance (S) are to be increased until the shunt resistance (S) is 2 ohms and the series resistance (R) is such that the galvanometer deflection lies between 8 to 16 cm. of the scale. The reading of the scale corresponding to the sharp edge of the spot of light is noted. Similar reading of the scale corresponding to the same sharp edge of the spot of light is noted by reversing the current. From the mean value of these two deflections the figure of merit is calculated by employing the equation (3) or (4).

(*iv*) The shunt resistance (S) is kept constant and another suitable series resistance (R) is applied to have the deflections both with direct and reversed currents within the specified range (*i.e.* within 8 to 16 cms.). From the mean value of these two deflections, the figure of merit is again calculated.

Distance between the galvanometer mirror and the scale is more different shunt resistances (say 2·5 ohms and 3 ohms) and for each shunt resistance two different series resistances are selected to have deflections within the specified range. The value of figure of merit is calculated in each case and from them the mean value of the figure of merit is found out.

Experimental data :

Distance between the galvanometer miror and the scale is $D=$......cm. [by a metre scale]

E.M.F. of the battery $=E=$......volts [by a voltmeter]

Resistance of the galvanometer $=G=$......ohms [given].

No. of obs.	Series resistance (R) in ohms	Shunt resistance (S) in ohms.	Deflections (d) in cm. with			Fig. of merit (m) in Amps/mm.	Mean Fig. of merit (m) in Amp/mm.	Sensibility $\theta=\frac{10^{-6}}{m}$ in mm./micro-amp.
			direct current	reversed current	Mean (d) in cm.			
1.	...	2	8·8	8·8	8·8	...		
2.	...	,,	...	...	...	...		
3.	...	2·5	...	...	...	...	...	...
4.	...	,,	...	...	...	....		
5.	....	3	...	...	...	...		
6.	...	,,	...	....	...			

Calculation :

$$\text{Fig. of merit}=m=\frac{D}{1000d}\times\frac{ES}{R(S+G)+SG}\ \text{Amp./mm.}$$

or, $m=$...... $=$......amp./mm.

or, $m'=m\times10^{6}=$......micro-amp./mm.

Sensibility $=\theta=10^{-6}/m=$...mm./micro-amp.

Precautions : (*i*) Before inserting the battery key, a high value of the series resistance R (say 10,000 Ω) and a low value of shunt resistance (S) should be applied to the galvanometer otherwise galvanometer will be damaged due to the passage of a heavy current.

(*ii*) The scale should be placed normal to the beam of light reflected from the mirror, otherwise deflections with direct and reversed currents will differ much.

(*iii*) To minimise the heat generated in the circuit the series resistance R should be high and the resistance of the shunt should be adjusted to have the desired deflection.

Oral Questions and their Answers

1. Define figure of merit of a suspended coil mirror galvanometer (see theory of the experiment).

2. Define sensitivity of a mirror galvanometer. What factors will increase the sensitivity of such a galvanometer ?

[See theory of this experiment.]

4. What kind of cell do you require to perform the experiment ?

A storage cell, having low internal resistance and a constant E.M.F. can only send a steady current and hence this cell must be used.

4. Will the figure of merit change when the distance between the scale and the mirror is altered ?

No, for the deflection obtained is reduced for a fixed distance of 100 cm. between the scale and the mirror. But the *deflection* will change with the change of that distance.

5. What is the function of the shunt which you apply ?

Shunt reduces the current through the galvanometer by allowing a large proportion of the main current to pass through its low resistance and by which the galvanometer is saved from damage.

6. Will the galvanometer deflection increase or decrease, when the shunt resistance is increased ?

Increase, for as the resistance of the alternative path of the current viz. shunt, is higher, greater fraction of the main current will flow through the galvanometer causing its deflection higher.

7. Why do you maintain the deflection between 8 to 16 cms. ?

[See question 2 of Expt. 41.]

8. What will be the resistance of a shunted galvanometer ?

Even less than the resistance of the shunt applied.

43. Determination of a high resistance by deflection method.

Connections of the apparatus : Connections are shown in Fig. 72. One terminal of the given high resistance (X) as well as of a high resistance box R (whose total resistance should be near about 20,0000 ohms) are connected to one pole of a storage battery B (which is usually 2 alkali cells in series), while the other terminals of high resistances X and R are respectively connected to the binding screws B_1 and B_2 of a two-way key. The third binding screw O of the two-way key is connected to the binding screw C_1 of a plug type commutator M, whose diagonally opposite binding screw C_2 is connected to the other pole of the battery B. By joining O with B_1 and B_2 alternately, the high resistance (X) and the resistance box R can be alternately inserted in the battery circuit. The second pair of diagonally opposite binding screws C_3 and C_4 of commutator M are connected to shunt box S containing altogether nearly 500 ohms resistance (whose value can be altered by one ohm). A mirror galvanometer G is connected parallel to the shunt box S.

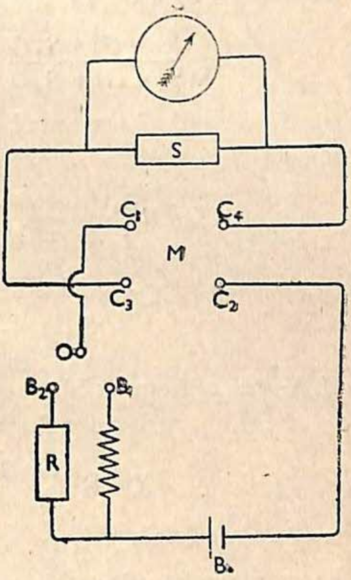

Fig. 72

Theory : Let d_1 cm. be the deflection of the galvanometer spot of light on the scale, when its shunt resistance is S_1 and the series resistance is X (unknown high resistance). The current C_g flowing through the galvanometer is given by,

$$C_g = \frac{ES_1}{X(S_1+G)+S_1G} = kd_1 \quad \cdots \quad \cdots \quad (1)$$

If d_2 cm. be the deflection of the galvanometer spot of light (d_2 is *nearly equal to* d_1) when its shunt resistance is S_2 and the series resistance is R (known), then the galvanometer current C'_g is given by,

$$C'_g = \frac{ES_2}{R(S_2+G)+S_2G} = kd_2 \quad \cdots \quad \cdots \quad (2)$$

Dividing (2) by (1) we get,

$$\frac{X(S_1+G)+S_1G}{R(S_2+G)+S_2G} \cdot \frac{S_2}{S_1} = \frac{d_2}{d_1}.$$

As S_1, S_2 and G are small in comparison with X and R, we can neglect S_1G and S_2G. Hence we get,

$$X = R\frac{S_1(S_2+G)}{S_2(S_1+G)} \times \frac{d_2}{d_1} \quad \cdots \quad \cdots \quad (3)$$

$$\text{or, } X = R\frac{S_2+G}{S_2\left(1+\dfrac{G}{S_1}\right)} \times \frac{d_2}{d_1} \quad \cdots \quad \cdots \quad (3a)$$

If X be extremely high so that deflection d_1 is obtained without the shunt resistance S_1 (*i.e.* by making $S_1 = \infty$) then,

$$X = R\frac{S_2+G}{S_2} \times \frac{d_2}{d_1} \quad \cdots \quad \cdots \quad (4)$$

The relation (3) or (4) [when X is very large and $S_1 = \infty$] may be employed to find the unknown high resistance X.

Procedure : (*i*) Connections are made as shown in Fig. 72 and a sharp edge of the spot of light is brought to the zero mark of the scale. A low resistance is inserted in the shunt box S and the unknown high resistance is inserted in the circuit by joining B_1 with O. The value of the shunt resistance is gradually increased to S_1, (say) until the deflection comes within the specified range *viz.*, 8 to 16 cms. of the scale. The current is then reversed and again the deflection is noted. The mean of these two deflections (say d_1) is found out.

(*ii*) Next the resistance in the shunt box is brought again to a very low value and the known high resistance R (which should not be *less than* 10,000 ohms) is inserted in the circuit by joining B_2 with O. The value of S is gradually increased to S_2 (say) until galvanometer deflection is *very nearly equal to the deflection* obtained in operation (*i*), when X was inserted in series with the circuit. Mean of the two deflections (say, d_2 which is nearly equal to d_1) with direct and reversed currents is determined. The first set of observation is now complete. By using the values of S_1, S_2, d_1 and d_2, X is calculated from (3) for G is given.

(*iii*) The operations (*i*) and (*ii*) are now alternately repeated to get three sets of observations in each of which the resistance R in the box is increased from that in the first observation and the shunt resistances are so altered that the deflections with X and R are of nearly equal order (but different from that obtained from first set of observation). The value of X is calculated from each set of observation and the mean of these values of X will be the value of unknown high resistance.

Experimental data :

E.M.F. of the storage battery used=.........volts.

Resistance of the galvanometer (given) G=.........ohms.

No. of obs.	Series resistance in ohms.	Shunt resistance in ohms.	Deflection in cm. with			Unknown resistance X in ohms.	Mean X in ohms
			direct current	reversed current	Mean		
1. (a)	(Unknown) X	24(S_1)	8·2	8·3	8·25(d_1)	...	...
(b)	(R-known) 11,000	6(S_2)	8·2	8·1	8·15(d_2)		
2. (a)	X	...(S_1)	....	...	...(d_1)	...	
(b)	(R) ...	...(S_2)	...	...	...(d_2)		
3. (a)	X	...(S_1)	...	...	...(d_1)	....	
(b)	(R)	...(S_2)	...	...	...(d_2)		

Calculations :

$$X = R\frac{S_1(S_2+G)}{S_2(S_1+G)} \times \frac{d_2}{d_1} = \quad \cdots \quad = \quad \cdots \qquad \text{ohms.}$$

Precautions : (*i*) As the constant k is different for different deflections, the pair of deflections (d_1 & d_2) for X and R for every set, should be made of the same order.

(*ii*) A storage battery should be connected in the circuit.

Oral Questions and their Answers

1. For measuring high resistance why do you prefer this method instead of Wheatstone bridge method ?

Wheatstone bridge becomes insensitive for very high and very low resistances. The bridge is suitable for the measurement of moderate resistance only.

2. Will your method be suitable for measuring the resistance of insulators ?

No ; In that case leakage of a charged condenser through the high resistance should be adopted to measure the resistance.

3. Would you take a storage cell or a Leclanche's cell ?

Whenever steady deflection is required, storage cell must be used for its *E. M.F.* is steady. Hence storage cells are to be used in this case. As the *E. M F.* of Leclanche's cell falls with time due to partial polarisation, it cannot be employed in cases where steady deflection is required.

4. What is the order of accuracy which you expect by this method of resistance-measurement ?

Order of accuracy is less than that obtained in Wheatstone bridge method.

5. Why do you make the pair of deflections with X and R almost equal ? (See precautions (*i*)].

44. Potentiometer and its action.

Construction : On a horizontal wooden board, a number of wires (usually ten) of uniform cross-section are fixed parallel to each other so that all are connected in series [Fig. 73]. The combination behaves as a single wire of length equal to the sum of the lengths of the wires. Binding screws B_1 and B_2 are fixed to the free ends of the first and the last wire. A brass strip

RR, provided with binding screws B_3 and B_4, is fixed along-side the last wire. There is a raised platform at one edge of the board, near the first wire, over which a metre scale is fixed. A jockey *J* can be moved along the wire so that its one leg *L* always touches the brass strip *RR*. By pressing the button *T* of the jockey, any point of the wire can be put in contact with the brass strip. The other legs of the jockey rest in a groove which runs near the platform and parallel to it. By means of an index mark *I*, the point of contact of the wire can be noted from the metre scale. The arrangement of potentiometer is shown in Fig. 73.

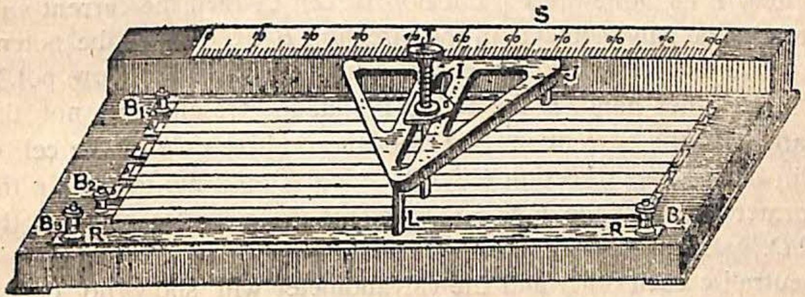

Fig. 73

Working principle : Potentiometer is employed to measure the potential difference only. Let the whole length (*L*) of the potentiometer wire be represented by B_1B_2, at the ends of which a battery *B* is joined through a key *K* and an extra resistance R_1.

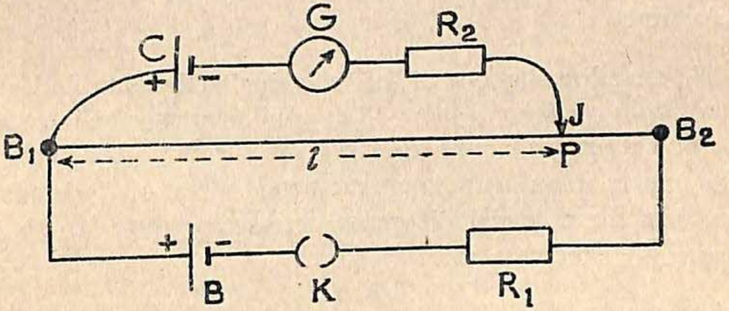

Fig. 73(*a*)

The positive of the battery B is joined to B_1 while its negative is joined to B_2 so that the current flows from B_1 to B_2 [Fig. 73(a)].

Let the positive terminal of another cell C be connected to B_1 while its negative terminal is joined to the jockey J through the galvanometer G and a high resistance R_2. The *E.M.F.* of the cell C is less than that of the battery B. When the jockey J is pressed at the point P of the potentiometer wire, two simultaneous currents flow in the galvanometer from opposite directions. If the battery B be alone present but not the cell C, then the current will flow in the galvanometer in the direction B_1CGJ under the potential difference existing between B_1 (high pot.) and P (low pot.). On the other hand, if the cell C be alone present but not the battery B, the current starting from the positive pole of the cell C will flow in the direction CB_1JG, which is opposite to that in the former case. If the *E.M.F.* ($=E_1$) of the cell C is equal to the *P.D.* existing between B_1 and P, then these two currents will neutralise each other and the galvanometer will show no deflection. At this balanced condition of the galvanometer we get,

$$E_1 = \rho l \qquad \ldots \qquad \ldots \quad (1)$$

Here, l ($=B_1P$) is the length of the potentiometer wire required for balance while ρ is the drop of potential per unit length of it. By determining ρ we can find E_1, the *E.M.F.* of the cell C.

To find ρ :

We can adopt any one of the following methods to find ρ :—

(a) *With a milliammeter* :—Let a milliammeter be introduced in the potentiometer circuit to record the current. If a current of i milli-ampere flows in the potentiometer wires of resistance R ohms, then the potential difference across the whole length L of the potentiometer wire is,

$$V = \frac{iR}{1000} \text{ volts.}$$

Hence,

$$\rho = \frac{V}{L} = \frac{iR}{1000L} \text{ volts per cm.}$$

(*b*) *By applying Ohm's law* :—If E be the *E.M.F.* of the battery B and R be the resistance of potentiometer wires, then the current flowing in the potentiometer circuit is,

$$i' = \frac{E}{R+R_1} \text{ amperes.}$$

Here R_1 is the extra resistance inserted in the potentiometer circuit. The *P. D.* across the whole length of the potentiometer wire is given by,

$$V = \frac{ER}{R+R_1} \text{ volts.}$$

$$\text{Hence,} \quad \rho = \frac{V}{L} = \frac{ER}{(R+R_1)L} \text{ volts per cm.}$$

(*c*) *With a cell of known e. m. f.* E_2 :—Let a standard cell of *E.M.F.* equal to E_2 be inserted in the galvanometer circuit B_1GJ. By moving the jockey J, the null point is obtained at a distance l' from the end B_1 of the potentiometer wire. The potential difference across the length l' of the potentiometer wire is therefore E_2. Hence we have,

$$\rho = \frac{E_2}{l'} \text{ volts per cm.}$$

45. General precautions to be taken in potentiometer experiments :

(*i*) *E.M.F. of the battery (B) employed in the potentiometer circuit must not change with time and hence a storage battery should be employed* [Fig. 73(*a*)]. The decrease of *E.M.F.* with time, will diminish the value of potential drop per unit length (ρ) and hence will cause a gradual increase of the distance of null point with the time.

(*ii*) *The positive of the potentiometer battery* (*B*) *and that of the E.M.F.* (*C*) *to be measured, must be joined to the same end* (B_1) *of the potentiometer wire* [Fig. 73(*a*)] ; otherwise the current due to the battery (*B*) and that of the battery (*C*) will flow in the same direction through the galvanometer giving no balance point at all. Hence the galvanometer will show deflections in the same direction when the jockey (*J*) is pressed both in the first and last wires of the potentiometer.

(iii) The value of the E.M.F. employed in the potentiometer circuit must be greater than the E.M.F. (or potential difference) to be measured; otherwise the potential drop created by the potentiometer battery (B), against the whole length of the potentiometer wire will not be sufficient to balance the *E.M.F.* to be measured and the galvanometer will show deflections in the same direction when the jockey (J) is pressed both at the beginning of first wire and at the end of last wire of the potentiometer.

(*iv*) Even after taking the above precautions, if we get the galvanometer deflections in the same direction both in the first and last wires, then we must infer that the current in the potentiometer circuit is small which makes the value of ρ (potential drop per cm.) also small so that the potential drop even over the whole length of the potentiometer wire is insufficient to balance the given *E.M.F.* To remove this difficulty, the potentiometer current should be increased by lowering the resistance of the rheostat resistance R_1 [Fig. 73(*a*)].

(v) for greater accuracy, the first null point should be adjusted near the middle of the last wire. If the null point is obtained at shorter length of the potentiometer wire then we must infer that the potentiometer current is large which has made the value of ρ also large and hence the potential drop over the shorter length balances the given *E.M.F.* In this case the potentiometer current is to be decreased gradually (by increasing the resistance of the rheostat R_1) until the balance point is obtained near the middle of last wire.

For subsequent observations, the potentiometer current is to be increased to get the null point at the last but one wire and then at the last but two wires.

(*vi*) At the beginning of the experiment, the high resistance R_2, (nearly, 10000 Ω must be inserted in the galvanometer circuit for the safety of the galvanometer [Fig. 73(*a*)]. For the sake of greater accuracy, the sensitiveness of the galvanometer may be increased (if necessary) by *making the value of R_2 equal to zero after the approximate balance point is attained.* [If with this high value of R_2 in the galvanometer circuit, the galvanometer gives a readable deflection by shifting the jockey by 1 or 2 mm. from the balance point then the value of R_2 should not be made equal to zero].

(*vii*) When the *E.M.F.* to be measured lies within a certain range, the potentiometer current should be so adjusted that the *null point for the highest E.M.F. of the range may be obtained at the last wire.* The balance points for the other lower *E.M.F* will be automatically obtained [as in the case of thermo-couple experiment].

(*viii*) *The potentiometer circuit should be kept closed only for the time which is necessary to find a null point,* otherwise the null point will shift due to the heating of the potentiometer wire. After finding one null point, the key (*K*) should be kept open for 2 or 3 minutes before the next null point is determined.

(*ix*) A galvanometer of *low resistance* (of the order of 50 ohms) is suitable for potentiometer experiments so that the potential sensitivity of the galvanometer may be high.

46. Determination of the E.M.F. of a cell by using a milliammeter and a potentiometer of known resistance.

Connections of the apparatus : Connections are shown in Fig. 74.

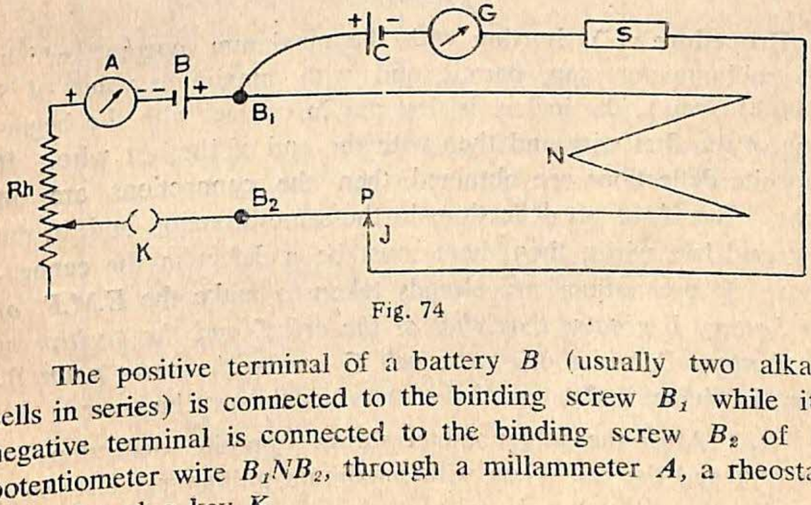

Fig. 74

The positive terminal of a battery *B* (usually two alkali cells in series) is connected to the binding screw B_1 while its negative terminal is connected to the binding screw B_2 of a potentiometer wire B_1NB_2, through a millammeter *A*, a rheostat *Rh* and a plug key *K*.

The positive terminal of the cell C whose *E.M.F.* (E) is required, is connected to the binding screw B_1 while its negative terminal goes to one end of the galvanometer G. The other terminal of the galvanometer is connected to the jockey J through a series high resistance S (about 10000 ohms). The milliammeter will record the current flowing in the potentiometer wires and the magnitude of this current can be altered by the rheostat Rh. The series high resistance S in the galvanometer circuit is a guard against the strong current through the galvanometer.

Theory : If a steady current of i milliamperes flows through the potentiometer wire of resistance R ohms and of total length L cm. (L is usually 1000 cm.) then the potential drop across the terminals of the potentiometer wire is $V=\frac{iR}{1000}$ volts. Hence the potential drop per unit length of the potentiometer wire is $\rho=\frac{iR}{1000L}$ volts./cm.

If the *E.M.F.* (E) of a cell (C) is balanced by the potential difference existing over a length l ($=B_1NJ$) of the potentiometer wire, then the *E.M.F.* of the cell is given by,

$$E=\rho l=\frac{iRl}{1000L}\text{ volts.} \qquad \ldots \qquad \ldots \qquad (1)$$

Procedure : (*i*) Starting with the maximum current which the miliammeter can permit and with maximum value of S (10000 ohms), the jockey is first put in contact with the beginning of the first wire and then with the end of the last wire. If opposite deflections are obtained, then the connections are all right. But if we get deflections in the same direction both in the first and last wires, then there must be a defect in the connections. If precautions are already taken to make the *E.M.F. of the battery B greater than that of the cell C and the positive of the battery B and that of the cell C are at the same point* B_1 then the defect is due to other causes which must be traced.

(*ii*) After the galvanometer shows opposite deflections in the first and the last wires with maximum milliammeter reading, the rheostat resistance is to be increased gradually to decrease the milliammeter reading until we get the null point at the la wire. This null point is noted thrice and the mean is found ou

(*iii*) The operation is then repeated by decreasing th rheostat resistance (*i.e.* by increasing the milliammeter reading until we get null points at the next two consecutive lower nur bered wires [*e.g.* If the potentiometer has 10 wires, then v shall first find the null point at 10*th* wire, and then at 9*th* ar 8*th* wires successively]. Each null point is noted three times.

(*iv*) Knowing these null points, the total length l of th potentiometer wire required for balancing in each case is fou out, from which the *E.M.F.* (E) of the cell is calculated b employing the relation (1).

The mean of these three values of E gives the unknov *E.M.F.*

Experimental data :

(*i*) Total length of the wires in the given potentiometer $L = 1000$ cms.

(*ii*) Resistance of the potentiometer wires $= R =$ ......ohn (given).

No. of obs.	Milliammeter readings (i) in milliamperes.	Null Points.			Total length of the pot. wire for balance in cm. (l)	*E.M.F.* of the cell is, $E=\frac{iRl}{1000L}$ volts	Mean *E.M.F.* in volts
		On wire number.	At the scale reading in cm.	Mean scale reading in cm.			
1.	50	10th	68·2 68·4 68·6	68·4	931·6	...	
2.	55	9th	....	...	...	...	...
3.	...	8th	... ...	...	...	...	

Calculations :

(*i*) $E = \frac{i\,Rl}{1000L} = \quad \cdots \quad = \quad \cdots$ volts (*ii*) E .. = ... = ... volts.

(*iii*) E .... = ... = ... volts.

Precautions : (*i*) In each case, the null point is to be first determined with the full value of S ($=10000$ ohms) and then to find the correct balance point the value of S may be made equal to zero provided the galvanometer is not sufficiently sensitive at the former arrangement.

[For other precautions, see Art. 45]

Oral Questions and their Answers

1. What are the essential requirements for the success of the experiment ?

The *E.M.F.* of the battery B must be greater than the *E.M.F.* of the cell C which is to be measured and the positive of these cells should be joined with the same binding screw (B_1).

2. Instead of employing a milliammeter, can you employ any other method for finding the *E.M.F.* of the cell ?

Yes : determination of the potential drop per unit length (ρ) of potentiometer wire will enable us to find the *E.M.F.* of the cell by the formula $E=\rho l$. Now ρ can be determined by three methods. (See Art. 44)

3. Why do you not employ a voltmeter to measure the *E.M.F.* of the cell instead of this method ?

Voltmeter gives the potential drop in the external circuit only and *not* the potential drop in the internal circuit. Hence we cannot get the *E.M.F.* of the cell (which is equal to the sum of the potential drops in the internal and external circuits).

4. What is the difference between the *E.M.F.* and the potential difference ?

E.M.F. is the total driving force of current in the circuit and has got a definite direction. In a circuit, the sum of the potential drops in the external and internal parts gives the *E.M.F.* in the circuit. Potential difference between two points is the product of the current and the resistance between these two points. The magnitude and the direction of the potential difference thus depend on those of the current, but both the magnitude and the direction of the *E.M.F.* in a circuit are constant.

5. Explain the part which the resistance S in the galvanometer circuit plays. Will the presence of S change the null point ?

Resistance S reduces the current flowing through the galvanometer when the balance is not attained, by which the galvanometer is saved from damage. When balance is obtained, the presence or absence of S will not affect the null point. Hence for sensitiveness of the arrangement S may be cut off from the galvanometer circuit when balance is nearly attained, provided the arrangement is not sufficiently sensitive. Another purpose served by the presence of high resistance S is, that when the balance is not obtained, the potentiometer current remains fairly unchanged when the jockey is put in contact with the potentiometer wire.

6. What should be the types of the cells which you should employ in B and C?

As the battery B is creating a constant potential drop per unit length of the potentiometer wire, its *E.M.F.* must be steady and hence this battery must be a storage battery. When balance is obtained no current is flowing from the cell C and it does not matter whether the cell C is a constant cell (like Daniell and storage cell) or a cell whose *E.M.F.* decreases with time (such as Leclanche's cell) due to partial polarisation during the flow of current from the cell.

7. Supposing the connections are all right, if you get deflection in the same direction both in the first and the last wire, what should be your conclusion?

The current in the potentiometer circuit is so low that the total potential drop at the ends of the whole wire is less than the *E.M.F.* of the cell C. Hence the current in the potentiometer circuit should be increased so that the total potential drop in the circuit becomes greater than the *E.M.F.* (E) of the cell which is to be balanced.

8. Can you measure the internal resistance of the cell C by this arrangement?

Yes: the potential difference (E) between the terminals of the cell when it is not sending any current (*i.e.*, the *E.M.F.* of the cell) is measured in the usual way. Then the P.D. (e) between the two terminals of the cell, when they are short-circuited by a wire of resistance r, is again measured. Then $\frac{E}{e}=\frac{r'+r}{r}$ from which the internal resistance r' can be obtained.

9. Does the resistance of the cell (C) whose *E.M.F.* is to be measured affect the value of its *E.M.F.*?

No: for when the balance is obtained, the cell (C) is not sending any current and hence the value of *E.M.F.* is independent of the resistance of the cell.

47. Comparison of E.M.F. of two given cells or determination of the E.M.F. of one cell when that of the other is known.

Connections of the apparatus: A battery B (usually two alkali cells in series) is connected in series with a rheostat

Rh, a plug key K_1 and the potentiometer wire B_1NB_2. The positive of the battery *B* is connected to the binding screw B_1, while its negative terminal is joined to B_2 through the rheostat, *Rh* and the key K_1 [Fig. 75].

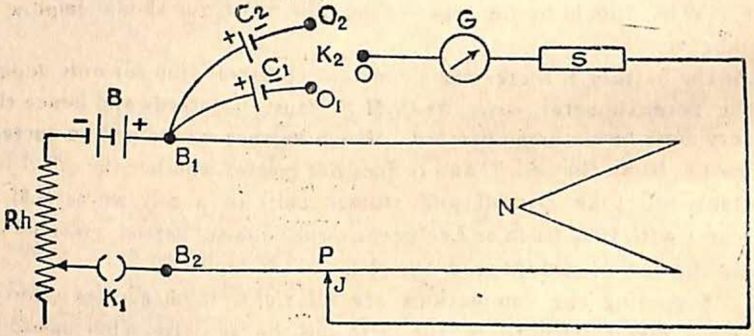

Fig. 75

The positives of two given cells C_1 and C_2 are connected to the binding screw B_1, where the positive of the battery *B* is also joined. The negatives of C_1 and C_2 are respectively connected to the binding screws O_1 and O_2 of a two way key K_2. The third binding screw *O* of the two-way key K_2 is connected to one terminal of the galvanometer *G* whose second terminal is joined to the jockey *J* through a fixed high resistance *S* (say 10000 ohms.)

Theory : Let the battery *B* in the potentiometer circuit, create a drop of potential ρ per unit length of the potentiometer wire by sending a constant current through it. If the cells C_1 and C_2 require lengths l_1 and l_2 respectively of the potentiometer wire for balance, then the *E.M.F's* E_1 and E_2 of the cells C_1 and C_2 are given by,

$$E_1 = \rho l_1 \; ; \quad E_2 = \rho l_2 .$$

$$\therefore \quad \frac{E_1}{E_2} = \frac{l_1}{l_2} \quad \text{or, } E_1 = \frac{l_1}{l_2} E_2 . \quad \cdots \quad \cdots \quad (1)$$

By finding l_1 and l_2 we can either compare E_1 and E_2 when both are unknown or we can find E_1 when E_2 is known, by employing the relation (1).

Procedure : (*i*) Connections are made as shown in Fig. 75. Starting with the zero resistance in the rheostat *Rh* and the maximum resistance of *S* (10000 ohms), the two cells C_1 and C_2 are alternately joined to the galvanometer. In each case the jockey *J* is put in contact with the first wire and last wire and if opposite deflections are obtained for both the cells, C_1 and C_2, then connections are to be supposed all right. But if we get the deflection in the same direction both in the first and the last wire for each of the two cells, then the connections must be wrong. If precautions are already taken to *make the E.M.F. of the battery B greater than those of the cells C_1 and C_2 and the positives of cells C_1 and C_2 and that of the battery B are at the same point B_1*, then the defect is due to other causes which must be traced.

(*ii*) After the galvanometer shows opposite deflections in the first and the last wire with each of the cells C_1 and C_2, the approximate positions of null points are to be determined for both the cells. In one case (say with the cell C_1) the null point will be at a longer distance than in the other (say with the cell C_2). Hence the *E.M.F.* (E_1) of the cell C_1 is greater than that (E_2) of the cell C_2. Now the rheostat resistance is increased until we get the null point in the last wire with the higher *E.M.F.* (E_1) of the cell C_1. This null point is noted thrice and the mean value (l_1) is found out.

Next the cell C_2 of the lower *E.M.F.* (E_2) is joined with the galvanometer and *without altering anything* the null point for this cell is also found out thrice and the mean value (l_2) is found out.

(*iii*) The operation (*ii*) is then repeated by decreasing the rheostat resistance (*i.e.* by increasing the potentiometer current) until the balance point for the higher *E.M.F.* (E_1) of the cell C_1 shifts to the next two consecutive lower numbered wires [*e.g.* If the potentiometer has ten wires, then observations should be made by changing the rheostat resistance so that the higher *E.M.F.* of the cell C_1 gives the null point at the 10th, 9th and 8th wires successively]. For finding the balance point for C_2 in each case, *the adjustments made for C_1 must be maintained.*

(*iv*) The ratio of l_1/l_2 is to be found out in each case and the mean of the three ratios gives the value of E_1/E_2. If E_2 is known we can find E_1 by using the relation (1).

Experimental data :

No. of obs.	Cell	Null points,			Total length of potentiometer wire for balance (in cm.)	$\frac{E_1}{E_2}=\frac{l_1}{l_2}$	Mean $\frac{E_1}{E_2}=m$
		On wire number	At the scale reading (in cm.)	Mean scale reading (in cm.)			
1.	First (E_1) ($E_1>E_2$)	10th	74·5 74·6 74·8	74·6	925·4(l_1)	1·4	
	Second (E_2)	7th	61·2 61·3 61	61·2	661·2(l_2)		
2.	First (E_1)	9th	... ...	...	...(l_1)	...	...
	Second (E_2)	...	... ...	...	...(l_2)		
3.	First (E_1)	8th	... ...	...	...(l_1)	...	
	Second (E_2)	...	... ...	...	...(l_2)		

Calculations :

$$\frac{E_1}{E_2} = m\ ; \quad \text{or,} \quad E_1 = mE_2 = \text{volts},$$

Precautions : [Same as in *Expt.* 46]

Oral Questions and their Answers

1. Suppose after proper connections, you get opposite deflections in the first and in the last wire for one cell only, but not so for the other cell. What would you do then ?

The current sent by the battery B in the potentiometer circuit is such that the total potential drop across the potentiometer wire is greater than the *E.M.F.* of one cell but less than that of the other. In this case, potentiometer current is to be increased (by diminishing, the rheostat resistance) so that the total potential drop across the whole potentiometer wire may be greater than the higher *E.M.F.* of the two cells.

2. Can you find the potential drop (ρ) per unit length of the wire when the *E.M.F.* of one cell is known.

Yes : From the theory, $E_1 = \rho l_1$, or, $\rho = E_1/l_1$. If E_1 is known then knowing l_1, we can find ρ.

3. If the null point obtained changes with time, then what should be your conclusion ?

If the current is sent in the potentiometer circuit continuously, then due to the heat generated, the resistance of the wires changes and as a result the null point changes. Hence the potentiometer circuit should be kept closed only for the time during which the null point is determined. To get the correct result, the circuit should be kept open for some time after the determination of a null point and then it should be closed momentarily to check the null point (or to find the new null point if necessary). After a few repetition, the null point will be found constant. This change of null point may also be due to the falling *E.M.F.* of the battery which should be checked previously. In case of falling *E.M.F.* the null point may increase (if the *E.M.F.* of B falls) or decrease (if the *E.M.F.* of C_1 or C_2 falls) while for heating the null point decreases with time.

48. To measure the current flowing in a circuit, by measuring the drop of potential across a known resistance inserted in the circuit, with the help of a potentiometer.

(a) When a cell of known E.M.F. is given for calibration. :

Connections of the apparatus : The apparatus consists of two circuits, viz.—(1) circuit containing unknown current, and (2) potentiometer circuit.

contact at the beginning of the first wire and at the end of the last wire, but it might so happen that the balance point will be obtained at the first wire only, when a very small current flows in r.

To increase the sensitiveness, the rheostat resistances R' is decreased (if alteration of current in r is permissible) until the $P.D.$ between the fixed resistance r increases to such a value that the balance point for this $P.D.$ across r, is obtained at least at the 7th or 8th wire (when ten wires are present). *This value of the rheostat in R' is to be kept constant throughout the experiment* so that the current flowing in r may remain constant. [If a *given current* flowing in r is to be measured then R' cannot be changed and null point against r should be noted wherever it is obtained]. This null point for the $P.D.$ e across r is noted thrice and the mean (l_2) is found out.

(*iv*) The above operations (*ii*) and (*iii*) constitute only one observation with the cell C of $E.M.F.$ (E) and the $P.D.$ (e) across the given resistance r for a particular value of ρ (the potential drop per unit length of the potentiometer wire). Such observations are to be repeated thrice for different increasing values of ρ (which can be done by decreasing the rheostat resistance Rh and hence by increasing the potentiometer current).

For this purpose, the resistance in the rheostat Rh is decreased successively until the balance point for the higher $E.M.F.$ (E) of the cell C shifts from the 10th to the 9th and then to the 8th wires (when the number of wires in the potentiometer are ten only). The corresponding null point for the $P.D.$ 'e' across r for each specific value of ρ is also determined *without any alteration of the value of R'*. Each null point is noted thrice and the mean is taken.

(*v*) Thus for each value of ρ, we get balanced lengths l_1 and l_2 for the cell C of $E.M.F.$ 'E' and for the $P.D.$ 'e' existing across the given resistance r respectively. Finding e in each case the mean value is determined which when divided by r, we get the current in the given circuit.

E.M.F. of the known cell $C=E=$.....volts
Given resistance (usually 10 ohms) in the circuit$=r=$..... ohms.

Experimental data :

No. of obs.	For P. D. existing across.	Null points,			Total length of potentiometer wire for balance (in cm.)	$e=E\frac{l_2}{l_1}$ in volts	Mean (e) in volts	Current $=i=\frac{e}{r}$ amperes
		On wire no.	At the scale reading (in cm)	Mean scale reading (in cm.)				
1.	Cell C (known E)	10th.	28·6 28·4 28·1	28·4	971·6(l_1)	·804		
	Resistance r (e)	8th.	76·4 76·6 76·8	76·6	723·4(l_2)			
2.	Cell C (known E)	9th.	....	....	....(l_1)	...	...	....
	Resistance r (e)	....	... .	...	....(l_2)			
3.	Cell C (known E)	8th.	... ...	....	...(l_1)	...		
	Resistance r (e)	....	....	...	...(l_2)			

Calculation :

$$i = \frac{\text{mean } e}{r} = \quad \ldots \quad = \quad \ldots \quad \text{Amperes.}$$

Precautions : (*i*) For greater sensitiveness, the approximate null point is to be first determined by giving full value of the resistance S (10000 Ω) and then the exact null point is to be determined by making S equal to zero, *provided the former arrangement is not sufficiently sensitive.*

(*ii*) When the null point for the cell C is to be determined, the key K_2 should be kept open to avoid the heating of the circuit containing r, by the unnecessary flow of the current.

(*iii*) For finding a null point, the key K_1 in the potentiometer circuit should be kept closed so long as it is required.

(*iv*) After finding a null point, the key K_1 should be kept open for sometime until the next operation is performed, so that the heat generated in the former operation may go away during this time.

(b) When a Milliammeter is given for calibration :

Connections of the apparatus : (1) *In the unknown current circuit,* a battery B' (usually two alkali cells in series) is joined in series with a plug key K_2, a rheostat R' and a fixed resistance r(=10 ohms, say) so that they form a complete circuit [Fig. 77].

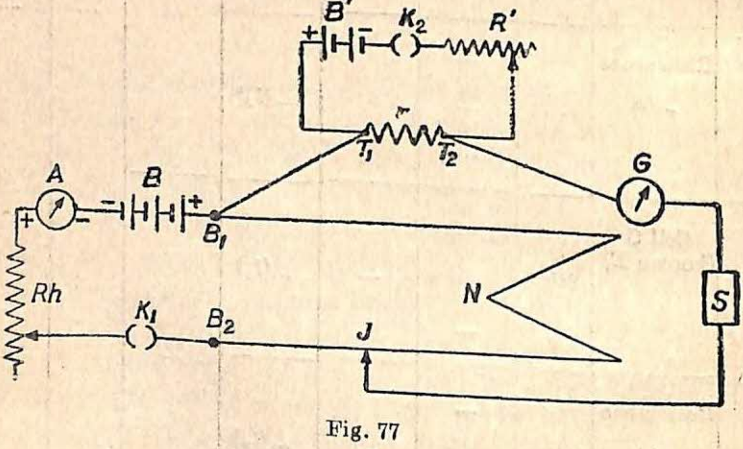

Fig. 77

(2) *In the potentiometer circuit,* the positive of the battery B (usually three alkali cells in series) is joined to the binding screw B_1 of the potentiometer wire B_1NB_2, while its negative terminal is connected to the negative of a milliammeter A. The wire from the positive of the milliammeter A is then connected to the binding screw B_2 of the potentiometer wire through the rheostat Rh and a plug key K_1. The arrangement is shown in Fig. 77.

To *interlink* the two circuits, the positive terminal T_1 of the fixed resistance r is joined to the binding screw B_1 of the potentiometer wire while its negative terminal T_2 is joined to one terminal of the galvanometer G. The other terminal of the galvanometer G is joined to the jockey J through a series high resistance S (=10000 ohms).

Theory : If a steady current of I milliamperes flows through the potentiometer wire of resistance R ohms and total length L cm. then the potential drop per cm. length of the potentiometer wire is given by,

$$\rho = \frac{IR}{1000\ L} \text{ volts per cm.}$$

If the potential difference e at the ends of the fixed resistance r, is balanced by the potential drop existing over the length l cm. $(=B_1NJ)$ of the potentiometer wire then, $e = \rho l = \dfrac{IRl}{1000\ L}$ volts.

Thus the current flowing in the resistance r or in the circuit containing r is given by $i = e/r$ amperes.

Procedure : (*i*) to (*iii*)—[same as in Expt. 46 ; only read 'against the fixed resistance r' for 'of the cell C'].

(*iv*) Knowing these null points, the total length l of the potentiometer wire required to obtain balance in each case is found out and from this, the potential difference e existing across the fixed resistance r is calculated. The mean of these three values of e when divided by the value of the fixed resistance r we get the current in amperes in the given circuit.

Experimental data :

(*i*) Total length of the wire in the given potentiometer is $=L=1000$ cms.

(*ii*) Resistance of the potentiometer wires $=R=$.........ohms (given).

No. of Obs.	Milliammeter readings (I)	Null points, On wire number	Null points, At the scale reading in cm.	Null points, Mean scale reading in cm.	Total length of the potentiometer wire for balance in cm. (l)	P. D. against the fixed resistance r is, $e=\frac{IRl}{1000L}$ volts.	Mean e in volts	Current is, $i=\frac{e}{r}$ amp.
1.	...	10th.	... ...	...	....	....	...	....
2.	...	9th.	....	...	...	...		
3.	...	8th.	... ...	...	...	...		

Calculations :

(*i*) $e=\frac{IRl}{1000\,L}=$ ... $=$ ... volts.

(*ii*) $e=$ ...... $=$ ...... volts.

(*iii*) $e=$ ...... $=$ ...... volts.

(*iv*) $i=e/r=$ ...... $=$ ...... Amperes.

Precautions : [Same as in Expt. 46].

Oral Questions and their Answers

1. In this experiment do you really measure current or P.D. ?

We actually measure the P.D. across a known resistance and when this P.D. is divided by the known resistance we get the current.

2. How many methods are known to you for measuring a current ?

Methods based on (1) Magnetic effects of electric currents such as suspended magnet and coil type galvanometer. (ii) Heating effect of current such as hot wire ammeter, thermo-galvanometer and (iii) Chemical effects of current such as copper and silver voltameters. Of these, the instruments based on (i) and (iii) can be employed to measure direct current only while the instruments based on (ii) can be employed to measure both direct and alternating currents. Potentiometer method is *unsuitable* for measuring alternating current.

3. What are the practical units of current and potential difference ?

Ampere and Volt are respectively the practical units of current and P.D. They are related by Ohm's law as Ampere = volt/ohm.

4. Why do you attempt to take null point at the last wire ?

This will make the percentage error in the result small. If there be an error in measuring the length by a small amount, the error introduced in the result is not much, when the balanced length is large.

5. Suppose after proper connections you get opposite deflections with the P.D. across r but not with the cell C What would you do then ? [See question 1 of Expt. 47.]

6. Can you measure resistance by a potentiometer ?

Yes ; for if we can measure the P.D. (e) across the unknown resistance (r) then we can find r from Ohm's law $r = e/i$. The current i in the unknown resistance can be determined by introducing a copper voltameter in the circuit.

7. Suppose your null point shifts with time. What are the causes for this ? [See question 3 of Expt. 47.]

49. Determination of the value of J, the mechanical equivalent of heat, by electrical method.

Connections of the apparatus :

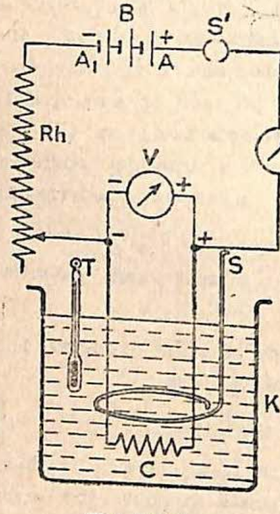

Fig. 78(a)

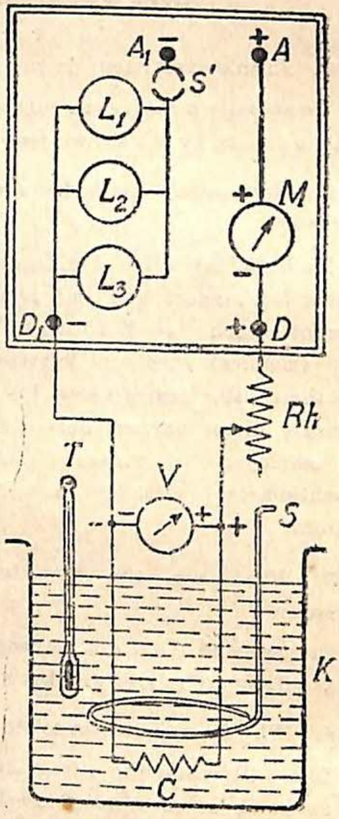

Fig. 78(b)

(*a*) *By employing storage battery.*—Connections of the apparatus are shown in Fig. 78(*a*) when a battery is employed to send current.

A battery *B* (usually several storage cells joined in series), a key *S'*, an ammeter *M*, a heating coil *C* and a rheostat *Rh* are all connected in series. The heating coil *C* is kept immersed in oil taken in a calorimeter *K* provided with a stirrer *S* and a thermometer *T*. The calorimeter is kept inside a wooden box packed with cotton wool. A voltmeter *V* is connected parallel to the heating coil *C* to measure the potential difference at its ends. The positive terminal (*A*) of the battery is joined to the positive of the ammeter M. [If the positive and negative of the ammeter or of the voltmeter are wrongly connected, then on starting the current, the pointer of one whose positive and negative are wrongly connected will not indicate any deflection. By such observation, the positive and negative of the ammeter or of the voltmeter can be correctly connected]. But *care should be taken not to connect the ammeter in the place of the voltmeter, for* in that case the ammeter will be destroyed. The rheostat Rh should be adjusted to get a suitable heating current which should lie between 1 and 2 amperes.

(*b*) *By employing D.C. mains.*—Fig. 78 (*b*) shows the connections, when the current is taken from the direct current main of the laboratory. At first, the live terminal of the main should be found out.* The switch S' and the lamp board containing the lamps L_1, L_2 etc. should be placed in the live terminal to prevent the possibility of getting a shock. Then the wires leading from D_1 and D should be introduced in water to find which one is positive.† The wires from D and D_1 should be joined through a rheostat Rh, to the heating coil C kept immersed in the oil of the calorimeter K provided with a stirrer S and a thermometer T. The voltmeter V is connected parallel to the heating coil. The ammeter M should be joined in series with the circuit so that its positive is connected to the positive of the main. This ammeter may be fixed on the board or it may be joined between the terminal D of the board and one terminal of the rheostat Rh.

When the switch S' is made on, the current flows in the circuit and the number of lamps L_1, L_2, etc. and the rheostat Rh are adjusted to get a suitable heating current (between 1 and 2 amperes). A small adjustment of current is done by the rheostat *Rh*.

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* For this purpose one terminal of a testing lamp should be earthed while its other terminal should be alternately introduced in the two holes of the plug point. That plug hole, at which the lamp glows is the live terminal of the main.

† When the wires from D and D_1 are introduced in the tap water taken in a beaker, profuse liberation of hydrogen gas occurs at the negative terminal due to the decomposition of water. Thus we can identify the negative and positive terminals.

Theory : If a current of C amperes be made to flow for t seconds through a heating coil having a potential difference of E volts at its ends, then the heat generated in the coil during the interval of time t is given by,

$$H = \frac{ECt}{J} \times 10^7 \text{ calories} \quad \ldots\ldots \quad \text{----} \quad (1)$$

where J is the mechanical equivalent of heat in *ergs per calorie.*

If the whole of heat thus generated be given to the calorimeter and the oil in it, then their temperature will rise from θ_1°C. to θ_2°C. Hence the heat taken up by the calorimeter and the oil in it, is also given by,

$$H = (m_1 s_1 + ms)(\theta_2 - \theta_1) \quad \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots \quad (2)$$

Here, m =mass of oil in the calorimeter,
m_1 =mass of the calorimeter and the stirrer,
s =sp. heat of oil,
s_1 =sp. heat of the calorimeter and the stirrer.

From (1) and (2) we get (by assuming no loss of heat),

$$\frac{ECt}{J} \times 10^7 = (ms + m_1 s_1)(\theta_2 - \theta_1)$$

or, $$J = \frac{ECt \times 10^7}{(ms + m_1 s_1)(\theta_2 - \theta_1)} \text{ ergs/calorie.}$$

or, $$J = \frac{ECt}{(ms + m_1 s_1)(\theta_2 - \theta_1)} \text{ joules/calorie} \quad \cdots \quad (3)$$

Procedure : (*i*) The calorimeter and the stirrer are first cleaned by a cotton pad and then weighed empty. Let this mass be m_1 gms. Some quantity of oil (say paraffin oil), which is sufficient to dip the heating coil completely, is taken in the calorimeter and the two together are weighed in a balance. Let this mass be m_2 gms. The mass of oil taken is $m = (m_2 - m_1)$ gms.

(*ii*) The calorimeter is then introduced in the circuit and connections are made as shown in the figure. [If the heating current is to be supplied by a storage battery (containing 5 or 6 alkali cells in series), then connections are to be made as shown in Fig. 78(*a*). But if the heating current is to be supplied from a *D.C.* main through parallel lamp resistances, then connections are to be made as shown in Fig. 78 (*b*)]. The thermometer *T* capable of reading $^1/_{10}$°*C*. is introduced in such a way that its bulb is near the middle region of the volume of the liquid but not in contact with the heating coil.

(*iii*) For a preliminary adjustment, the circuit is closed for a *small interval of time* and the variable resistance [either the rheostat *Rh* only for Fig. 78(*a*) or both the lamp resistance and rheostat resistance *Rh* for Fig. 78(*b*)] are adjusted until the desired current (between 1 and 2 amperes) is recorded by the ammeter. After this adjustment is complete, the current in the circuit is made off and the liquid is continually stirred to have its temperature steady. When the temperature is maintained steady for at least five minutes, its value θ_1 is noted from the thermometer *T*. [By this preliminary adjustment, the correct placing of positive and negative terminals of both the ammeter and the voltmeter can be detected. If the terminals of any one or both are wrongly placed, then the pointer will move in the opposite direction and by this observation, they can be placed properly].

(*ii*) Now the stop-clock and the current in the circuit are started simultaneously and the liquid is kept stirred continuously. The readings of thermometer, the ammeter and the voltmeter are noted after an interval of one minute until the rise of temperature between 6°*C* and 8°*C* is observed. This time the current in the circuit is stopped and the exact time *t* at which the current is made off, is also noted, but the *stop-clock is not stopped*, it is allowed to run on. The thermometer reading goes on increasing for sometime and the actual time t_0, at which the thermometer records the maximum temperature θ_2, is also noted. The stirring of the liquid is to be continued and its temperature is to be noted *just at the time* $(t_0+t_0/2)$. If the temperature at this time [*viz.*, at time $(t_0+t_0/2)$] be θ_3, then the fall of temperature in time $t_0/2$ is, $x=(\theta_2-\theta_3)$. Thus the maximum temperature θ_2, when corrected for the loss of heat by radiation, will be given by, $\theta'=(\theta_2+x)$. Hence the rise of temperature of liquid by the flow of current in the circuit for *t* seconds is $(\theta'-\theta_1)=(\theta_2-\theta_1)+x]$.*

2. What precautions would you adopt to minimise the loss of heat by radiation.

The current should be such (between 1 to 2 amp.) that the rise of temperature between 6°C to 8°C should occur in the short interval (about 4 to 6 minutes) of time. For further correction some observations are to be made [see procedure].

3. What precaution would you take so that the current in your circuit may remain fairly steady ?

The given current (between 1 and 2 amperes) is to be obtained by applying a high E.M.F. and a high series resistance in the circuit so that the increase of the resistance of the heating coil with the rise of its temperature may not change the current materially.

4. Can you measure sp. heat of a liquid by this method ?

Yes ; for if J is known, then sp. heat s of the liquid can be determined from the relation (3).

5. Is it desirable to have greater or smaller mass of liquid in the calorimeter ?

The amount of liquid should be just sufficient to dip the heating coil in it. If a large quantity of liquid be taken, then a long time will be necessary to raise the temperature within the desired range and hence loss of heat by radiation will be greater.

6. What is the difference between an ammeter and a voltmeter ?

Ammeter is a low resistance (for reasons see Art. 25) portable galvanometer while a voltmeter is a high resistance (see Art. 25) galvanometer.

7. Can you convert one to the other ?

Yes ; by applying series high resistance to the ammeter, it can be converted to a voltmeter while the voltmeter can be converted to an ammeter by applying a low resistance shunt to it.

8. How does the flow of electric current through a conductor generate heat and what are the factors which govern the generation of heat ?

The flow of electricity through a conductor having a resistance is obstructed and hence electric current will have to do some work against the resistance and this work is converted to heat. Heat generated is proportional, to the square of current, to the resistance of the conductor and to the time of flow of current.

9. Instead of D.C. if you send A.C. in the circuit, then what will happen ?

Heat will still be generated but the D.C. ammeters and voltmeters should be replaced by hot wire ammeters and voltmeters. In that case ammeters and voltmeters will record virtual amperes and virtual volts.

10. How would you identify which one is the live terminal and which one is the positive terminal ?

[See foot notes of connections of item (*b*), of this Expt.]

50. Determination of the temperature-coefficient of resistance of the material of a given wire.

(a) By using a metre bridge :

Ordinary metre bridge may be employed to find the resistance of the given wire at different temperatures. As the resistance of the connecting wires and the end resistances of the bridge wire are ignored, we cannot expect greater accuracy of the result obtained by this arrangement.

Connections of the apparatus : The plan of connections is shown in Fig. 79. In this figure, *R* is the given wire which is joined to the gap G_2 of the metre bridge through two connecting wires $L_1P_1M_1$ and $L_2P_2M_2$. These connecting wires should be of such *minimum length* as is required (after placing the

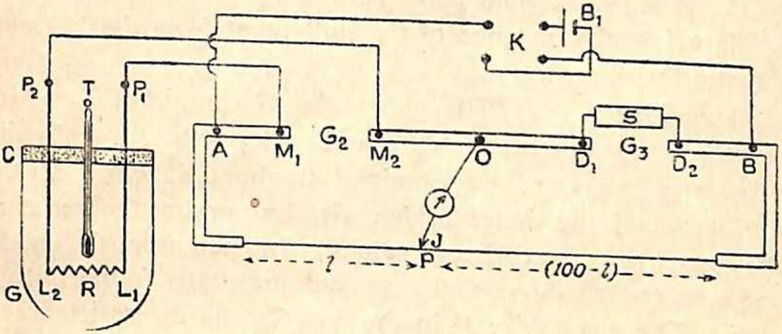

Fig. 79

tube *G* near the middle of the metre bridge) for interchanging the gaps without causing any shift of the glass tube *G* which contains the given wire *R*. A thermometer *T* is introduced inside the tube *G* to record the temperature of the wire. The mouth of the tube is closed by a cork *C*. A resistance box *S* (containing fractional ohms) is joined to the gap G_3. A battery B_1 (usually a Leclanche's cell or a single storage cell) is joined to the extreme binding screws *A* and *B* of the metre bridge through a commutator *K*. The two terminals of a galvanometer are joined to the binding screw at *O* and to the jockey *J*. If necessary, the glass tube *G* can be inserted inside a hypsometer to raise its temperature by steam.

Theory : If R_1 and R_2 be the resistances of a wire at temperatures t_1°*C*. (low) and t_2°*C*. (high), then within this small range of temperature we may write,

$$R_1=R_0\ (1+\alpha t_1) \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

$$R_2=R_0\ (1+\alpha t_2) \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

By simplifying the relations (1) and (2) we get,

$$\alpha=\frac{R_2-R_1}{R_1t_2-R_2t_1} \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

By measuring the resistances R_1 and R_2 of the given wire at temperatures t_1°*C*. and t_2°*C*. respectively we can find α the temperature-coefficient of the material of the wire, from the relation (3). The resistance of the given wire can be calculated from the Wheatstone bridge principle *viz.*,

$$\frac{\text{Res. in the left gap}}{\text{Res. in the right gap}}=\frac{l}{100-l} \quad \ldots \quad \ldots \quad (4)$$

Here l is the distance of the null point from the left end of the metre bridge wire.

Procedure : (*i*) The glass tube *G* containing the wire is kept at room temperature t_1°*C*. and null points, for both direct and reversed currents, are obtained at about 45 cms., 50 cms., and 55 cms., of the metre bridge wire by varying the resistances in the box *S* to three different values. In each case, the mean of the null points for direct and reversed currents is found out.

(*ii*) The given wire *R* in the gap G_2 and the resistance box *S* in the gap G_3 are then interchanged. Null points for both direct and reversed currents are again noted by inserting successively those three resistances in the box *S* which were formerly applied in operation (*i*). The mean of the two null points (one for direct current and another for reversed current) is again determined for each of the three resistances in the box *S*.

(*iii*) The resistance of the given wire is then *separately* calculated in each of the six cases (three cases before and three cases after the interchange of *R* and *S*) by employing the relation (4) and the mean of these six values, gives R_1.

(*iv*) The glass tube *G* with the given wire in it is now inserted in the hypsometer. The tube *G* is then heated by steam formed by boiling the water in the hypsometer. When the temperature $t_2\,^\circ C$. recorded by the thermometer T remains steady for at least five minutes, the resistance R_2 of the given wire at this temperature is determined by repeating the operations (*i*), (*ii*) and (*iii*) as before. Knowing R_1 and R_2 we can calculate α from the relation (3).

Experimental data :

Temp.	No. of obs.	Resistance in ohms applied in,		Null points in cms. with			Unknown resistance in ohms	Mean resistance in ohms.
		left gap	right gap	direct current	reversed current	Mean		
	1.	R	1·8	44·6	44·8	44·7	1·45	
	2.	,,	...	...	...	...	...	
30°C.	3.	,,	...	...	...	...	...	...
$=t_1\,^\circ C$	4.	1·8	R	54·4	54·6	54·5	1·5	$=R_1$
	5.	...	,,	...	...	...	...	
	6.	...	,,	...	...	...	...	
	1.	R	...	...	...	...	...	
	2.	,,	...	...	...	...	...	
...	3.	,,	...	...	...	...	...	$=R_2$
$=t_2\,^\circ C$	4.	...	R	...	...	...	...	
	5.	...	,,	...	...	...	...	
	6.	...	,,	...	...	...	...	

Calculation :

$$\alpha = \frac{R_2 - R_1}{R_1 t_2 - R_2 t_1} = \quad \dots \quad = \quad \text{per } ^\circ C$$

(b) By using Carey Foster's bridge :

In this arrangement, the effects of the resistances of the connecting wires and the end resistances of the metre bridge wire are eliminated and hence this method gives more accurate result than that obtained by metre bridge.

Connections of the apparatus :

The plan of connections is shown in Fig. 80. The ends of the given wire *R*, whose temperature-coefficient of resistance is required, are soldered to two long connecting wires $L_1P_1M_1$ and $L_2P_2M_2$. The wire $D_1C_1DC_2D_2$ is called the compensating wire whose resistance *r* is equal to the sum of the resistances of the connecting wires $L_1P_1M_1$ and $L_2P_2M_2$. These connecting wires and the compensating wire are made sufficiently long so that their respective ends M_1M_2 and D_1D_2 can interchange the gaps without causing any shift of the glass tube *G*, which is placed near the middle of the bridge. The mouth of *G* is closed by a cork *C*. A thermometer *T* is inserted in the tube *G* to record the temperature of the wire. The terminals M_1 and M_2 of the given wire are connected to one extreme gap (say extreme left gap G_1) while the terminals D_1 and D_2 of the compensating wire are connected to the other extreme gap (say extreme right gap G_4) through a resistance box *S* (containing fractional ohms) in series. Two resistance coils Q_1 and Q_2 (usually each equal to 1 ohm) are respectively connected to the two middle gaps G_2 and G_3 respectively. The terminals of a battery B_1 (usually a Leclanche's cell or a storage cell) are connected to the binding screws at *A* and *B* through a commutator *K*. The terminals of a galvanometer are joined to the binding screw at *O* and to the

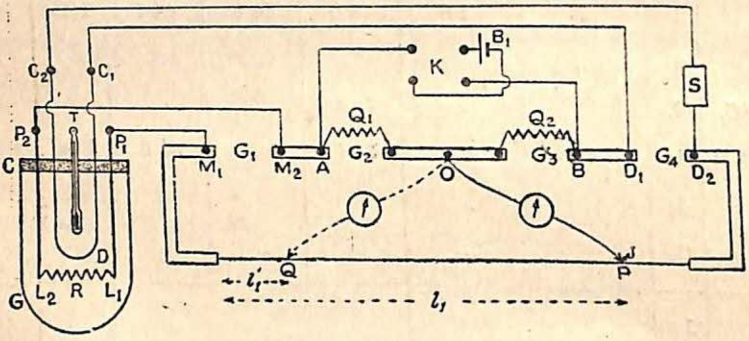

Fig. 80

jockey *J* moving over the bridge wire. The glass tube *G* can be introduced inside a hypsometer when required.

Theory : With connections as shown in Fig. 80, let the resistances in the box *S* be varied and made equal to S_1 until the null point is obtained at one extremity *P* of the bridge wire whose distance from the left end is l_1 cm. Hence we may write,

$$\frac{Q_1}{Q_2}=\frac{r+R+\lambda_1+l_1\rho}{r+S_1+\lambda_2+(100-l_1)\rho}$$

where λ_1 and λ_2 are the end resistances at the left and right ends of the bridge respectively and ρ is the resistance per unit length of the bridge wire,

$$\text{or,}\quad \frac{Q_1}{Q_1+Q_2}=\frac{r+R+\lambda_1+l_1\rho}{2r+R+S_1+\lambda_1+\lambda_2+100\rho} \quad \cdots \quad (1)$$

Let the compensating wire together with the resistance box *S* in series with it, be now interchanged with the given wire *R* and the new null point is obtained at *Q* at a distance l_1' from the left end. Proceeding as before, we may write,

$$\frac{Q_1}{Q_1+Q_2}=\frac{r+S_1+\lambda_1+l_1'\rho}{2r+R+S_1+\lambda_1+\lambda_2+100\rho} \quad \cdots \quad (2)$$

From (1) and (2) we get,

$$r+R+\lambda_1+l_1\rho=r+S_1+\lambda_1+l'_1\rho$$

$$\text{or,}\quad R=S_1+(l'_1-l_1)\rho \quad \cdots \quad \cdots \quad (3)$$

Keeping the temperature of the given wire *R* constant, the value of the resistance in the box *S* is changed from S_1 to S_2 to get another pair of null points at l_2 (when *R* and *S* are respectively in the gaps G_1 and G_4) and at l'_2 (when *R* and *S* are respectively in the gaps G_4 and G_1). Then as in eqn. (3) we may write,

$$R=S_2+(l'_2-l_2)\rho \quad \cdots \quad \cdots \quad (4)$$

From (3) and (4) we get,

$$S_1+(l'_1-l_1)\rho=S_2+(l'_2-l_2)\rho$$

$$\text{or,}\quad \rho=\frac{S_2-S_1}{(l'_1-l_1)-(l'_2-l_2)} \quad \cdots \quad \cdots \quad (5$$

The relation (5) is employed to find ρ. Then from this known value of ρ, *R* can be calculated from the relation (3).

If the given wire has the resistances R_1 and R_2 at temperature t_1°C. and t_2°C., then the temperature-coefficient of resistance is given by,

$$\alpha=\frac{R_2-R_1}{R_1t_2-R_2t_1} \quad \dots \quad \dots \quad (6)$$

Procedure : (*i*) The given wire R is kept at room temperature and the resistance in the box S is changed until at a particular value (say S_1) we get the null point at that extremity of the wire at which the box is situated. The null points are determined both for direct and reversed currents and the mean null point is found out.

(*ii*) The operation (*i*) is repeated for two other different values of resistances in the box S at which the null point shifts by steps of 5 cms. towards the middle of the bridge wire. In every case the mean of the two null points for direct and reversed currents is found out.

(*iii*) The positions of R and S (together with the compensating wire connected to S) are now interchanged and those three resistances which were formerly inserted in the box S, are now successively applied and in each case null points are determined both for direct and reversed currents. From this, the mean null points in each case is found out.

(*iv*) Taking pairs of the three observations, as shown in the table viz.—observations 1 and 2, 1 and 3, also 2 and 3, ρ is calculated by using the relation (5) and the mean of these three values of ρ is found out. By substituting this mean value of ρ in equation (3), three values of R_1 are determined from the pair of data obtained in each observation, (with R and S in two extreme gaps then by inter-changing their gaps). The mean of these three values of R_1 gives correct R_1.

(*v*) The glass tube G is next kept in a hypsometer and water in it is boiled to produce steam. When the temperature indicated by the thermometer T is remaining steady for at least five minutes the operations (*i*), (*ii*) and (*iii*) are repeated. From the data so obtained, mean R_2 is calculated in a manner similar to that adopted in calculating R_1. [explained in item, (*iv*)].

(*iv*) Knowing R_1 and R_2 α is calculated from the relation (6).

Experimental data :

[Numerical figures in the table are for illustrations only.]

Temp	No. of obs.	Res. in the extreme left gap in ohms.	Res. in the extreme right gap in ohms.	Null points in cms. with			Mean Res. per unit length (ρ)	Unknown resistance in ohms.	Mean resistance in ohms.
				direct current	reversed current	Mean			
30°C	1	(a) R	$3{\cdot}4(S_1)$	95	95	95 $=l_1$		1·6	
		(b) $3{\cdot}4\ (S_1)$	R	5·2	5	5·1 $=l'_1$	·02		
	2	(a) R	$3{\cdot}2\ (S_2)$	90	90	90 $=l_2$	ohms/cm.		...
$=t_1$°C		(b) $3{\cdot}2(S_2)$	R	10·1	10	10·05 $=l'_2$		1·6	$=R_1$
	3	(a) R	... (S_3)	...	....	.... $=l_3$			
		(b)...(S_3)	R	...	...	... $=l'_3$		...	
	1	(a) R	... (S_1)	...	...	... $=l_1$		...	
		(b)....(S_1)	R	...	...	... $=l'_1$	....		
... $=t_2$°C	2	(a) R	... (S_2)	...	...	... $=l_2$	ohms/cm.		...
		(b)....(S_2)	R	...	...	... $=l'_2$		...	$=R_2$
	3	(a) R	... (S_3)	...	...	.... $=l_3$			
		(b)...(S_3)	R	...	..	.... $=l'_3$		...	

NB [Observations (*a*) are taken first and the observations (*b*) are taken later.]

Calculations :

$$(i)\quad \rho=\frac{S_2-S_1}{(l'_1-l_1)-(l'_2-l_2)}=\frac{3{\cdot}2-3{\cdot}4}{(5{\cdot}1-95)-(10{\cdot}1-90)}={\cdot}02\ \text{ohms/cm.}$$

$$(ii)\quad R=S_1+(l'_1-l_1)\rho \qquad =3{\cdot}4+(5{\cdot}1-95)\times{\cdot}02$$

$$=3{\cdot}4-1{\cdot}8=1{\cdot}6\ \text{ohms.}\qquad \text{etc.}$$

$$(iii)\ \alpha=\frac{R_2-R_1}{R_1t_2-R_2t_1}=\qquad\cdots\qquad=\qquad\cdots\qquad \text{per}^\circ C$$

Precautions : (*i*) The battery key should be closed for the minimum time necessary for finding a null point, otherwise the resistance will change due to heating.

(*ii*) The temperature indicated by the thermometer must remain steady for at least five minutes before the null point is noted.

(*iii*) The temperature coefficient so determined is the mean value of the coefficient within the range from t_1°C to t_2°C.

(*iv*) The length of the connecting wires and the compensating wire must be just sufficient so that their ends may reach any gap of the metre bridge without any displacement of the position of the glass tube G (kept near the middle of the bridge) which contains the given wire.

Oral Questions and their Answers

1. What do you mean by the term temperature-coefficient of resistance and what is its unit ?

The increase in resistance of unit resistance for 1°C, rise of temperature is defined as the temperature-coefficient of resistance. It is expressed in – per °C.

2. What is the cause of the variation of resistance of a metal with temperature ?

Conduction in metals is due to the directive movement of free electrons in the metal under a P.D. When the temperature rises, the directive motion of electrons decreases and their random motion increases which decreases the current strength or increases the resistance.

3. Can you name a substance whose resistance decreases with temperature ?

Electrolytes and carbon show a negative temperature-coefficient of resistance.

4. What is the most important practical application of the variation of resistance with temperature ?

Variation of resistance of metals (specially platinum) is utilised in measuring temperatures within a long range.

5. Why do you employ the compensating wire ?

This eliminates the resistance of the lead wires connected to the given wire.

6. Which method you would prefer to measure the resistance of a wire at various temperatures ?

Callender and Griffith's bridge is the best arrangement to measure the resistance of given wire at various temperatures. Carey Foster's bridge may also be employed with accuracy.

7. Is the temperature-coefficient of resistance the same at all temperatures ?

No ; its value is different at different temperatures and that is why we call it the mean temperature-coefficient of resistance within a specified range of temperature.

51. To measure the resistance of electric lamps (a) at room temperature, (b) and at rated current.

(a) *Lamp-resistance when cold*: The resistance of an electric lamp at room temperature can be measured by employing a P. O. box.

Connections of the apparatus : The electric lamp is introduced in a socket provided with two binding screws. This lamp is joined in the fourth arm of the P. O. box. The battery and the galvanometer are connected in the usual manner [for details of connections see experiment with P. O. box Art. 29]

Theory : If Q, P and R be respectively the resistances in the first, second and third arms of the P. O. box, then for no deflection of the galvanometer the resistance S of the lamp is, by the Wheatstone bridge principle, given as,

$$\frac{P}{Q}=\frac{R}{S} \quad \text{or,} \quad S=\frac{Q}{P}R \qquad \cdots \quad (1)$$

The relation (1) is employed to measure the resistance S of lamp at room temperature.

Procedure : [Same as in Expt. with P. O. box; Art. 29, but perform the operations with the ratio $Q : P$ as 100 : 100 and 100 : 1000 only.]

Experimental data :

[Same as in Expt. with P. O. box, Art. 29. When one lamp is given write S_1 for r_1 and omit the columns of r_2, R_1 and R_2, but when two lamps are given write S_1 for r_1 and S_2 (resistance of second lamp) for r_2 and omit the columns of R_1 and R_2].

(b) *Lamp-resistance when hot* : The simplest method of measuring the resistance of a lamp when hot, is to employ an ammeter and a voltmeter.

Connection of the apparatus : One terminal of the main (say $+ve$) is joined to one terminal T_1 of the lamp through an ammeter A (having a range $0-5$ Amperes reading up to ·1 Ampere) and a rheostat Rh (having a high current bearing capacity). The other terminal of the main (say $-ve$) is joined to other terminal T_2 of the lamp through a switch K (placed in the live wire). A voltmeter (of range $0-250$ volts) is connected parallel to the lamp. The connections are shown in Fig. 81.

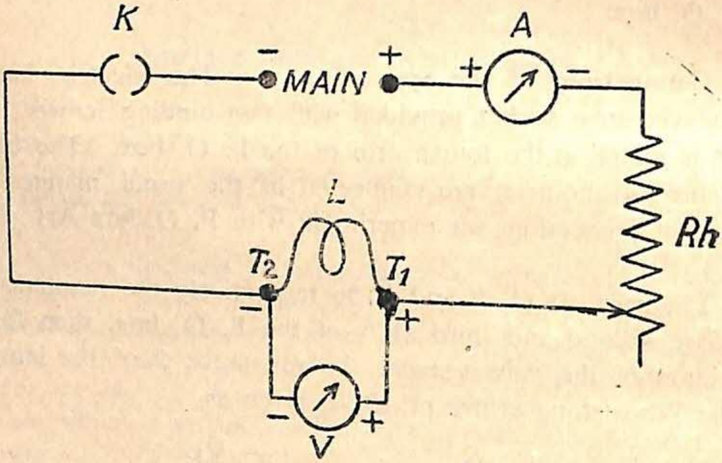

Fig. 81

[N.B. The resistance in the rheostat Rh is to be made zero, when the resistance of the lamp at the voltage of the main is required.]

Theory : If C amperes current flow through the lamp under a potential difference of E volts, then by Ohm's law the resistance S' of the lamp is given by, $S'=E/C$ ohms .... (2)

The relation (2) is employed to find the resistance S' of the lamp when hot.

Procedure : (*i*) At first the positive and the negative terminals of the D.C. main are ascertained by introducing the free ends of the two wires coming from the plug in a beaker containing tap water. The terminal at which there is a profuse liberation of the gas (Hydrogen), is the negative terminal.

(*ii*) The ends of the wires are then joined in series with the given ammeter, a rheostat *Rh* (if the resistance of the lamp for different current strengths in it, is required) and the lamp *L*, so that the positive of the main is in connection with the positive of the ammeter. The voltmeter *V* is connected parallel to the lamp.

(*iii*) After switching on the circuit, the readings of the ammeter and voltmeter are noted from which the resistance of the lamp, when hot, is calculated by using the relation (2).

(*iv*) If the variation of resistance of the lamp for different values of current in it is required then the resistance of the rheostat *Rh* is altered from a very high value to zero value and in each case the ratio of the potential difference (E) at the ends of the lamp (obtained by voltmeter) and the current (C) flowing through it (obtained by an ammeter reading up to ·1 amp.) gives the resistance (S') of the lamp. Then a graph may be drawn by plotting current (C) in amperes flowing through the lamp along abscissa and the corresponding resistance (S) along ordinate. This graph will show the variation of resistance of the lamp with current flowing through it.

(*v*) The experiment may be performed with two lamps, the filament of one of which is carbon while that of another is a metal, say, tungsten. In the case of carbon the resistance decreases with the increase of current in it while in the case of a metal the resistance increases with current.

Experimental data :

Bulb no.	No. of obs.	Rheostat resistance	Ammeter reading (C) in Amp	Voltmeter reading (E) in volts	Res. of the lamp in ohms $= S' = E/C$
1 Carbon lamp	1	infinity	0	0	...(S_1) when cold
	2	V. high	....	...	....(S_1') ,, hot
	3	high	...	...	...(S_1'') ,, ,,
	etc.	etc.	etc.	etc.	etc.
	6	zero	....	....	... ,, V. hot
2 Metal filament lamp	1	infinity	0	0	...(S_2) when cold
	2	V. high	...	...	...(S_2') ,, hot
	etc.	etc.	etc.	etc.	etc.

[N.B. For one observation only, make the experiment with zero rheostat resistance.]

Oral Questions and their Answers

1. What are the advantages and disadvantages of this method ?

The advantage of this method is that it is very simple and the value of the resistance can be quickly obtained. The disadvantage is that the method is not an accurate one.

2. Will the resistance of the lamp be greater or less when hot than when cold ?

For a metallic filament lamp, the resistance is greater while hot, but for carbon filament lamp the resistance is low while hot than when cold ?

3. If an extra resistance be inserted in the circuit, then will the resistance of the lamp be the same as before ?

No ; for by the insertion of the extra resistance, the current flowing through the lamp will be less and the temperature of the filament will also be less. As a result, the resistance of the metallic filament lamp will be decreased while that of the carbon filament will be increased.

4. What is the relation between the resistance R_0 of a metallic wire at 0°C, and its resistance R_t and t°C. ?

The relation is given by, $R_t = R_0 (1+\alpha t+\beta t^2)$, where α and β are constants.

52. To study the variation of thermo-e.m.f. of a thermo-couple with temperature and to determine the melting point of a solid with its help.

Construction of thermo-couple : The couple ordinarily employed is copper-constantan couple which gives about 40 microvolts per °C. It consists of three pieces of wires, each is about 1 metre long. Of these three wires, two are of copper while the third is of constantan. The two ends of constantan are kept soldered to one end of each of the two copper wires. Two glass tubes T_1 and T_2 are kept introduced in the copper wires to be sure that the metals touch at the junctions only. The couple is shown in the Fig. 82. [This couple should be supplied to the students for performing the experiment].

Connections of the Apparatus : The connections are shown in Fig. 82. The apparatus consists of two circuits, viz. (1) thermo-couple circuit and (2) potentiometer circuit. These two circuits will then be interlinked.

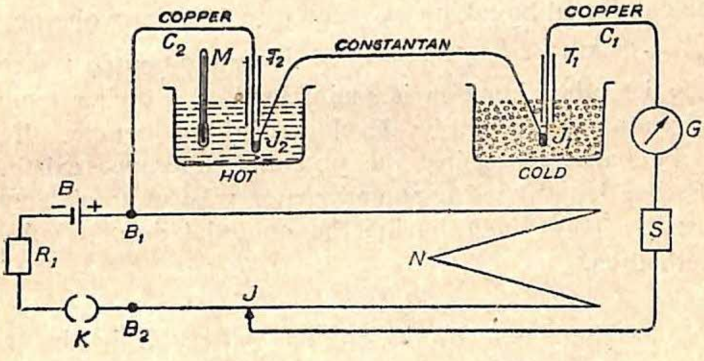

Fig. 82

(1) The junction J_1 of the couple is kept at the middle of a beaker filled with powdered ice mixed with a little water to fill up the air spaces. The junctions J_2 of the couple is kept at the middle region of water taken in another large beaker [for the current flows from constantan to copper at the hot junction J_2]. The temperature of this water can be varied and the temperature

at any stage can be measured by a thermometer M reading [1/10]°C.

(2) The potentiometer circuit is formed by joining the potentiometer wire B_1NB_2 in series with a plug key K, a resistance box R_1 and a battery B (usually one alkali cell). The $+ve$ of B is connected to B_1.

To interlink the two circuits, the copper wire C_1 from the cold junction J_1 is joined to the jockey J of potentiometer through a sensitive galvanometer G and a fixed high resistance $S(S=200$ ohms). [After finding an approximate null point, S should be made equal to zero to have the correct null point by increasing the sensitiveness of galvanometer.]

The copper wire C_2 from the hot junction J_2 is joined to the binding screw B_1 of potentiometer (where the $+ve$ of battery B is also joined). The value of R_1 should be such that the potential drop (ρ) per cm. of the potentiometer wire should be nearly 5 micro-volts ($=5\times10^{-6}$ volts) when the highest temperature of the hot junction (J_2) will not exceed 100°C. If the highest temperature of the hot junction exceeds 100°C then R_1 should be calculated by taking ρ equal to 10 microvolts per cm.

Theory : When one junction of a thermo-couple is kept at 0°C while its other junction is maintained at a higher temperature, a thermo-e.m.f. e will be developed in the couple. If this e.m.f. e be balanced against the potential difference existing at the ends of a length l of a potentiometer wire of total length L (L is usually 1000 cm.) having the potential drop ρ volts per unit length then,

$$e=\rho l \text{ volts} \qquad \ldots \quad (1)$$

If E be the e.m.f. of the storage battery B in the potentiometer circuit, R be the resistance of the potentiometer wire of length L, and R_1 be the external resistance in series with the potentiometer circuit then,

$$\rho=\frac{ER}{(R+R_1)L} \text{ volts per cm.} \qquad \ldots \qquad \ldots \quad (2)$$

From (1) and (2) we get,

$$e=\frac{ERl}{(R+R_1)L} \text{ volts} \qquad \ldots \qquad \ldots \qquad \ldots \quad (3)$$

By measuring the thermo-e.m.f. e with the help of the eqn. (3) for different temperatures of the hot junction a curve may be drawn by plotting temperature t (in °C) of the hot junction along x-axis, while the corresponding thermo-e.m.f. e along y-axis. Within a small range of temperature (which is far away from neutral temperature) the curve would be a straight line as is shown in Fig. 84 drawn from a sample data. This curve is called *calibration curve* of the given thermo-couple.

By introducing the hot junction (J_2) within a bath of unknown temperature (T°C) the corresponding thermo-e.m.f. e' for this unknown temperature T°C of the hot junction, can be calculated from (3) by finding the balanced length l' on the potentiometer wire. Knowing e', a horizontal line is drawn from the point e' on the y-axis to cut the curve at A [Fig. 84]. The ordinate drawn from A will cut the temperature-axis at D, whose value is T°C. Thus the unknown temperature T°C of the bath can be obtained from the graph.*

Procedure : (*i*) The resistance R of the potentiometer wire is measured by a $P.\,O.$ box (or the value of R should be supplied). The e.m.f. E of storage cell B in the potentiometer circuit is measured by an accurate voltmeter reading at least ·01 volts. The e.m.f. of the cell should be measured before and after the experiment to see whether E remained constant throughout the experiment.

(*ii*) The value of R_1 should be calculated from the relation (2) by assuming that ρ shall be 5 micro-volts ($=5\times10^{-6}$ volts) per cm, and the highest temperature of the hot junction shall not exceed 100°C. The temperature of cold junction is always maintained at 0°C. The *applied value of R_1 should be a round number near about the calculated value of R_1.*

---

* The unknown temperature T°C can also be calculated by employing any one of the two following formulae given by (4) and (5) when the thermo-e.m.f. e' corresponding to T°C is known. Thus,

$$e'=aT+bT^2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

$$e'=aT^b \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

To find the constants a and b, thermo e.m.f.'s e_1 and e_2 of the couple are to be known at two known temperatures t_1°C and t_2°C

[cont. at the foot of p. 252]

(*iii*) After making connections of the circuit in the manner shown in Fig. 82, the null point is noted several times when the junction J_2 is kept introduced into water at room temperature (t_1°C). The mean of these several null points (l_1) should be employed to calculate the thermo-e.m.f. (e_1) at room temperature (t_1°C) by using the eqn. (3).

(*iv*) The temperature of water (in which junction J_2 is kept introduced) is now raised by steps of 10°C and at each step, several null points are noted by constantly stirring the water and maintaining its temperature constant for at least 3 minutes. The mean value of these null points at each temperature is employed to calculate the thermo-e.m.f. at that temperature by using the equation (3). Proceeding in this way, the mean null point is determined at the maximum temperature (t_2°C) of water in the state of boilaing and hence the thermo-e.m.f. (e_2) at this temperature (t_2°C) is also calculated from (3).

(*v*) A graph is then constructed with the temperature (t°C) of the hot junction as the abscissa and the corresponding

---

(say room temperature t_1°C and boiling point t_2°C of water). Thus if eqn. (4) is to be employed to find T, we get from (4),

$$e_1 = at_1 + bt_1^2 \quad \dots \quad (6)$$

$$e_2 = at_2 + bt_2^2 \quad \dots \quad (7)$$

By solving (6) and (7) we get,

$$a = \frac{e_1 t_2^2 - e_2 t_1^2}{t_2 t_1 (t_2 - t_1)} \quad \dots \quad (8)$$

$$b = \frac{e_2 t_1 - e_1 t_2}{t_2 t_1 (t_2 - t_1)} \quad \dots \quad (9)$$

Again if eqn. (5) is to be employed to find T we get from (5),

$$e_1 = at_1^b \text{ and } e_2 = at_2^b \quad \dots \quad (10)$$

By solving the relations of (10) we get,

$$b = \frac{\log e_2 - \log e_1}{\log t_2 - \log t_1} \quad \dots \quad (11)$$

Knowing b from (11) the value of a can be obtained from the relation $a = \frac{e_1}{t_1^b}$ .... (12)

thermo-e.m.f. (e in millivolts) as the ordinate. This curve is called *calibration curve* of the thermo-couple. As the neutral temperature of the couple is far away from the highest temperature employed for hot junction, the curve would be a straight line (straight part of parabola) as shown in the curve of Fig. 84 drawn with a sample data.

(*vi*) To find the melting point of a solid, the hot junction J_2 is then introduced in the solid taken in a test tube. This test tube is introduced in the water bath whose temperature can be varied. The null points on the potentiometer wire is noted after an interval of one minute from the beginning of the melting of solid till whole of it melts. The same procedure of noting the null points after an interval of one minute is adopted from the beginning of freezing of liquid till whole of it is solidified.

(*vii*) Two curves are then drawn by plotting time along x-axis and corresponding null point along y-axis. The natures of these curves will be like those shown in Fig. 83 (a) [during melting of solid] and in Fig. 83(b) [during freezing of the liquid]. Both the curves will show a horizontal part when the melting or freezing of the substance is going on. The ordinate (l') of this horizontal part will be the actual null point. The mean of these two values of l' (one during melting and another

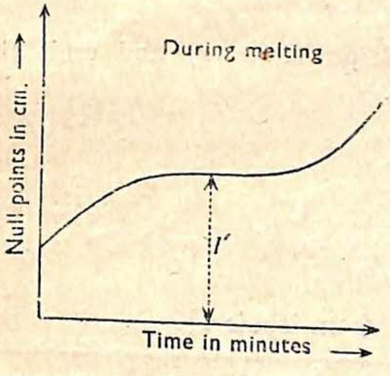

Fig. 83(a)

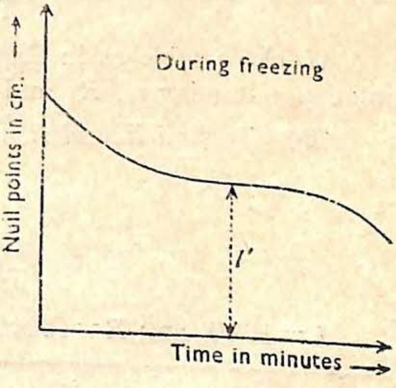

Fig. 83(b)

during freezing) should be employed to calculate the thermo-e.m.f. e' corresponding to the melting point $T°C$ of solid by using eqn. (3).

(*viii*) Knowing e' the corresponding temperature $T°C$ can be found from the graph [Fig. 84]. This unknown temperature $T°C$ can also be calculated from the relation (4) or (5) by determining constants a and b from the knowledge of thermo-e.m.f.'s e_1 and e_2 at room temperature $t_1°C$ and boiling point $t_2°C$ of water.

(*ix*) [If thermo-electric power $P\left(=\frac{de}{dT}\right)$ at a given temperature $\theta°C$ is required, an ordinate is to be drawn from a point on the abscissa whose value is $\theta°C$ [Fig. 84]. This ordinate will cut the curve at Q. As the curve is a straight line, the thermo-electric power at $\theta°C$ will given by,

$$P=\frac{de}{dt}=\tan\phi=\frac{QG}{HG}\cdot \text{ milli-volts}/°C.]$$

Experimental data :

(A) *Determination of the resistance* (R) *of pot. wire* :—

TABLE I

[Make a table as in Expt. 29; put R for r_1 and omit the colums containing r_2, R_1 and R_2].

(B) *To find E and* R_1 :—

TABLE II

L=1000 cm.; R=. . .ohms [from Table I].

E.M.F. (E) of cell B in volts			Approx. Res. (R'_1) required to make $\rho=5\times10^{-6}$ volts nearly per cm. is, $R'_1=\left(\frac{ER}{\rho L}-R\right)$ ohms	Actual value of R_1 applied in ohms
Before Expt.	After Expt.	Mean (E)		
...	...	...	...	...

(C) *Temp.—null point record* :—

TABLE III

Temp. of cold junction $=0°C$.

No. of obs.	Temperature of hot junction in °C.	Null points.			Total length of pot. wire reqd. for balance (l)	Potential drop per cm. $=\rho'=\dfrac{ER\times10^3}{(R+R_1)\,L}$ milli-volts.	Thermo-e.m.f. $e=l\rho'$ in milli-volts
		On wire number	At the scale reading in cm.	Mean scale reading in cm.			
1	(room temp. $=t_1$°C) ...	...	... ...	...	...	...	...(e_1)
2	...	...	... ...	...	...	,,	...
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.
8	($B.P.$ of water $=t_2$°C) ...	...	... ...	...	...	,,	...(e_2)

(D) *(Time)—(Null point) data during melting and freezing* :—

TABLE IV

Null points during melting				Null points during freezing			
Time in mins.	On wire No.	At the S.R. in cm.	Total length for null pt. in cm.	Time in mins.	On wire No.	At the S.R. in cm.	Total length for null pt. in cm.
0	...	....	...	0	...	...	...
1	....	...	...	1	...	...	...
2	...	...	...	2	...	...	...
3	...	...	...	3	...	...	...
4	...	....	...	4	...	...	...
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.

(E) *Drawings of* $(e-t)$ *curve* :—

Two curves are now drawn by plotting time along x-axis and its corresponding null points along *y-axis*, when the substance is melting and freezing. The nature of these curves will be as shown in Figs. 83(a) and 83(b). Both the curves will show a horizontal part, indicating that the null point and hence the temperature of the hot junction is remaining constant during melting and freezing of the substance. The mean of the ordinates of the horizontal parts of two curves is to be found out. Let this mean value be l'.

(F) *Drawings of* $(e-t)$ *curve* :—

To draw this curve, the temperature (t) of the hot junction in °C is plotted along x-axis while the corresponding thermo-e.m.f. (e) in milli-volts is plotted along y-axis. As the range of temperature is small and far away from neutral temperature, the curve would be a straight line (straight portion of parabola). To find unknown temperature $T°C$ for which thermo-e.m.f. is e', a point F is taken on the y-axis whose value is e'. A horizontal line drawn from F will cut the curve at A. The ordinate drawn from A will cut the temperature-axis at D, whose value will be the unknown temperature $T°C$. The curve shown in Fig. 84 is drawn from the sample data

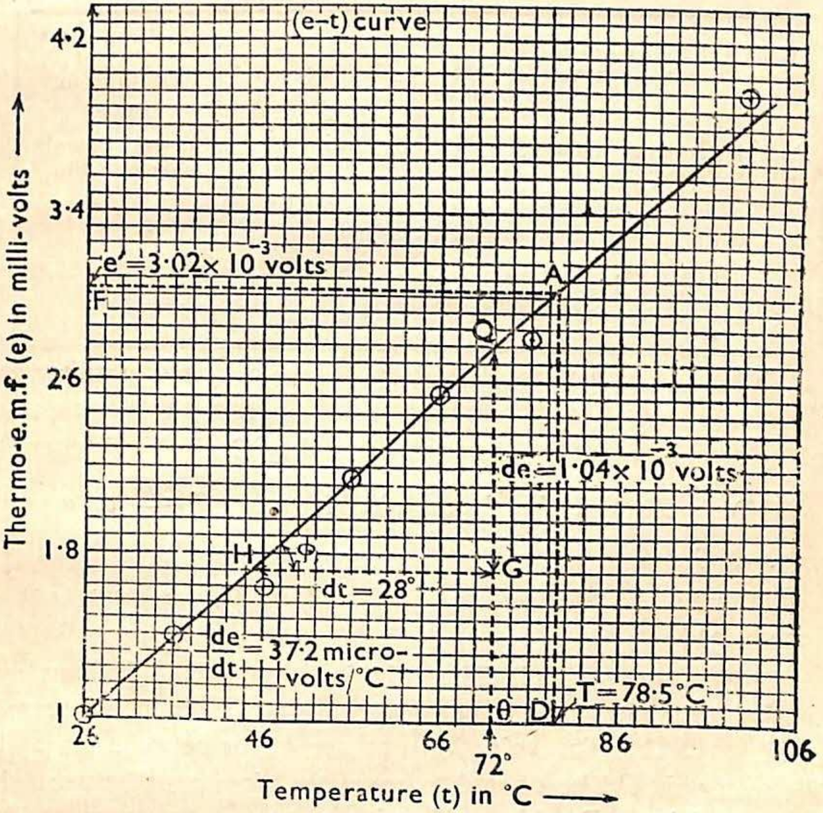

Fig. 84

given in Table V. Is this sample curve, the thermo-e.m.f. at the unknown temp. $(T°C)$ has been shown to be 3·02 milli-volts whose corresponding unknown temperature is $78{\cdot}5°C$.

TABLE V

Temp. (t) in °C →	26°	36°	46°	56°	66°	76°	100°
Thermo e.m.f.(e) in milli-volts →	1·013	1·375	1·644	2·167	2·537	2·796	3·955

(G) *Determination of the melting point of solid :—*

TABLE VI

Constant null point in cm. from the curves.			Value of ρ' in milli-volt from Table III	Thermo. e.m.f. at T°C. is $e'=l'\rho'$ in millivolt.	Melting point T°C. of solid from,	
During melting	During freezing	Mean (l')			($e-t$) curve	Calculation
...	...	...	...	...	...	...

N.B. [Calculation of T may be made by using either the relation (4) or (5) after finding a and b from the values of e_1 and e_2 in volts at t_1°C (room-temp.) and t_2°C (B.P. of water)].

[**(H)** *To find the thermo-electric power* $P=\frac{de}{dt}$ *at a given temp.* θ°C :—

(For finding the value of P at temp. θ°C, see item (*ix*) of procedure)]

Discussions : (*i*) The cold junction should be carefully guarded throughout the experiment, so that its temperature may remain at 0°C. To avoid the presence of air between ice particles, water should be poured to cover the air spaces between the particles of ice. By this, uniformity of temperature surrounding the cold junction is assured.

(*ii*) The water taken in the beaker (in which hot junction J_2 is introduced) should be large and it should be heated slowly so that the temperature may remain constant for an appreciable time.

(iii) The junctions (J_1 and J_2) should be kept at the middle region of the baths so that the temperatures of the junctions may not change due to a small variation of the temperature of the surroundings.

(*iv*) The experiment should be performed within a small range of temperature so that the $(e-t)$ curve within that range may be approximately straight.

(*v*) To guard against fall of potential of the battery B, during the experiment, its e.m.f. should be measured several times during the experiment.

(*vi*) The resistance R_1 should be made such, so that the null point may be obtained at the last wire, *provided that arrangement maintains sufficient sensitiveness* (*after making* $S=0$).

Oral Questions and their Answers

1. What are (*i*) Seebeck, (*ii*) Peltier and (*iii*) Thomson effects ?

(*i*) It is a phenomenon, in which electric current is produced by creating a difference of temperature between the two junctions of two dissimilar metals. (*ii*) It is a phenomenon, in which difference of temperature is created between the junctions by sending a current in a thermo-couple. (*iii*) It is a phenomenon, in which a P. D. is produced between the two points of the same conductor having a difference of temperature between them.

2. What is the neutral temperature of a couple ?

It is the temperature of the hot junction at which the thermo-e.m.f. generated in the couple is maximum, the cold junction being at 0°C.

3. What are the laws of (*i*) intermediate metals and (*ii*) intermediate temperatures ?

(*i*) The insertion of an additional metal into a thermo-couple will not alter the e.m.f. of the couple provided the additional metal is at the temp. of the point at which it is inserted. (*ii*) The e.m.f. of a couple with junctions at temps. T_1 and T_3 is the sum of the e.m.f.s of two couples of the same metals, one with junctions at temps. T_1 and T_2 and another with junctions at temps. T_2 and T_3.

4. What is the relationship between the thermo-e.m.f. (E) and temperature (t) ?

Within a small range of temperature, their relation is given by, $E=at+bt^2$, or, $E=atb$.

5. What are the practical applications of a thermo-couple ?

It is employed, (*i*) to measure high temperature, (*ii*) to construct sensitive milliammeters and galvanometers to measure small alternating current, (*iii*) for the measurement of radiant heat.

6. What is pyro-electricity ?—It is an electrical effect in which certain crystals, especially tourmaline, exhibit electrical charges when heated or cooled.

53. Triode valve and its action.

Construction : Triode valve consists of an evacuated glass bulb *B* containing (*i*) filament (*F*), (*ii*) a metal cylinder (*A*) called anode and (*iii*) a cylinder of wire gauge (*G*) known as the grid [Figs. 85(*a*) and 85(*b*)].

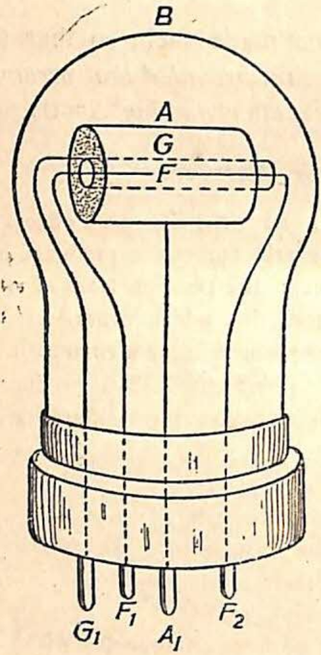

Fig. 85(*a*)

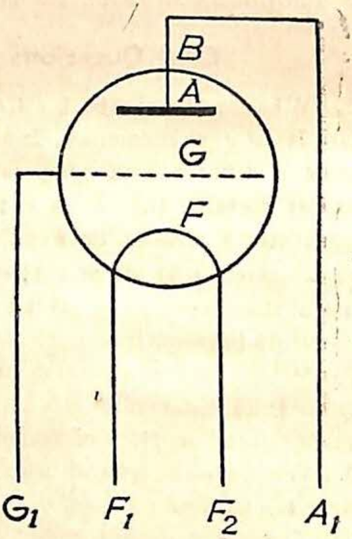

Fig 85(*b*)

(*i*) The filament *F* is a fine wire of tungsten the ends of which are joined to the two pins F_1 and F_2. By heating this filament with a steady current, thermo-electrons can be emitted from it. This atmosphere of thermo-electrons round the filament is known as the *space charge.*

(*ii*) The anode *A* is a metal cylinder whose axis coincides with the filament *F*. This cylinder is connected to another pin A_1. By applying a suitable positive potential to this cylinder, electrons from the filament or cathode can be dragged on it causing a current known as the *anode current.*

(*iii*) The grid G is a wire gauge cylinder which is co-axial with the anode A and is placed inside the anode surrounding the filament or cathode F. This is a control electrode by which the electrons from the cathode F can be accelerated or retarded by applying positive or negative potential to the grid respectively. The grid is connected to another pin G_1. Thus in the outside of the valve we get four pins which can be introduced within the four holes of a socket.

Action : When the $+ve$ and $-ve$ terminals of a battery B'_3 (usually of 4 volts *E.M.F.*) are respectively joined to the two terminals F_1 and F_2 of the filament (Fig. 86), it is heated and emits electrons. When the positive of a high tension battery B'_1 (say of 100 volts *E.M.F.*) is attached to A or A_1 while its negative is attached to F_2 (Figs. 85 and 86), the electrons round the cathode will be attracted by the anode A producing a current known as the *anode current*. Thus greater the value of the anode potential greater will be the value of anode current until saturation is reached. This current can be measured by a milliammeter (*M.A.*).

If now the positive of a battery B'_2 is joined to G or G_1 while its negative is joined to F_2, the electrons moving towards the anode will be accelerated and a greater number of them will attach on the anode within a short time causing an increase of anode current. On the other hand, if the negative of the battery B'_2 is joined to G or G_1 while its positive is joined to F_2 (Fig. 86) the electrons will be retarded and a less number of them will attach on the anode causing a decrease of anode current. At a certain $-ve$ potential of the grid, no electron will reach the anode producing no anode current.

If a graph be constructed with the grid voltage as the abscissa and anode current as the ordinate then the curve so obtained is called the *characteristic curve* of the triode. We get different characteristic curves for different anode voltages as are shown in Fig. 87.

54. To draw the characteristic curves of a triode and hence to find its (a) amplifying factor, (b) internal resistance and (c) mutual conductance.

Connections of the apparatus : Detailed connections of the circuit are shown in Fig. 86.

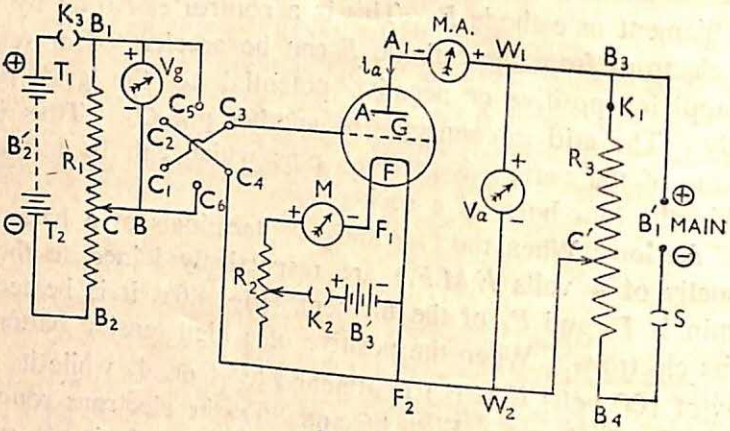

Fig. 86

(a) Anode connection : (*i*) *By using D. C. main.*—Suitable +*ve* potential (say 100 volts or more) may be applied to the anode A_1 (or A) by using a D.C. main (B'_1) as shown in Fig. 86. The +*ve* and −*ve* terminals as well as the live terminal of the main are first determined. By introducing a switch S in the live wire, the +*ve* and −*ve* terminals of the main are connected respectively to the ends B_3 and B_4 of a high resistance R_3 through the switch S. The +*ve* end B_3 of the wire R_3 is joined to the +*ve* terminal of a milliammeter (M. A.) by a wire W_1. The −*ve* terminal of the milliammeter should be joined to the anode A_1. One end of another wire W_2 is joined to one terminal F_2 of the filament while the other end of W_2 is joined to a clip C'. The clip C' can be connected to any point of the wire R_3 and by moving this clip towards or away from the −*ve* end B_4 of the wire R_3, greater or smaller *P.D.* can respectively be applied between the anode A_1 and filament F_2. The magnitude of this applied voltage can be obtained by connecting the +*ve* and −*ve* terminals of a voltmeter (V_a) to the wires W_1 and W_2 which go to the +*ve* terminals of the milliammeter and −*ve* terminal F_2 of the filament, respectively. The voltmeter should read from 0 to 230 volts.

(ii) *By using a battery.*—If a battery (either dry battery or storage battery which can supply P.D. up to 180 volts) is given then the high resistance wire R_3, the switch S, the connecting wires B'_1B_3 and B'_1SB_4 are not at all necessary. The given battery should be inserted in the place of high resistance wireR_3. The $+ve$ terminal of this battery should be connected to the $+ve$ of milliammeter (M. A.) through a key K_1 and connecting wire W_1. The $-ve$ of milliammeter should be connected to the anode A_1. The $-ve$ terminal of the battery should be kept free (*i.e.* it should not be connected to any thing). One end of another wire W_2 should be joined to the filament F_2 while the other end of W_2 should be joined to a clip C'. By connecting this clip C' to the $-ve$ pole of any cell of the battery a desired P.D. can be applied between the anode A_1 and the filament F_2. This P.D. will be greater or smaller according as the clip C' is moved towards or away from last $-ve$ of the battery. This applied P.D. between A_1 and F_2 can be measured by inserting a voltmeter (V_a) between W_1 and W_2. The $+ve$ of voltmeter should be connected to W_1, which joins the $+ve$ of milliammeter while the —ve of voltmeter should be joined to the wire W_2 (or filament F_2) which joins F_2. This voltmeter should read 0 to 230 volts.

(b) Filament connection : One terminal F_1 of the filament should be connected to the $+ve$ pole of a battery B'_3 (4 to 6 volts e.m.f.) through an ammeter (M), a rheostat (R_2) and a plug key (K_2). The $-ve$ pole of B'_3 should be joined to the $-ve$ terminal F_2 of the filament where one end of the wire W_2 (as well as the $-$ve of voltmeter V) is connected. Rheostat R_2 should be adjusted to pass a specified current (as directed by manufacturer) through the filament. This current can be obtained from the ammeter M.

(c) Grid connection : To apply suitable P.D. ($+ve$ or $-ve$) between the grid (G) and the filament (F_2), the $+ve$ terminal T_1 and $-ve$ terminal T_2 of a battery B'_2 (of about 30 volts e.m.f.) are respectively connected through a plug key K_3 to the two lower binding screws B_1 and B_2 of a sliding rheostat R_1 [for this rheostat see Fig. 38(a)]. The $+ve$ terminal B_1 of this rheostat is connected to one of the two middle mercury cups (C_5) of a Pohl commutator [for Phol commutator See Figs. 37(a) and 37(b)], while the other middle mercury cup (C_6) of the commutator is joined to the upper binding screw (B)

of the rheostat which is in connection with the sliding contact (C) [see Fig. 38 (a)]. The mercury cups C_3 and C_4 (which are on one side of the commutator) are respectively connected to the grid G and to the $-ve$ terminal F_2 of the filament. To measure the applied $P.D.$ between G and F_2 the $+ve$ and $-ve$ of a voltmeter V_g (reading 0 to 30 volts) are respectively connected to the binding screws B_1 and B of the rheostat (R_1). By moving the sliding contact (C) towards or away from B_1, smaller or greater P.D. can respectively be applied in the grid circuit. By turning the rocker of commutator towards C_3 C_4, $+ve$ potential can be applied to the grid while by turning the rocker of the commutator towards C_1C_2, $-ve$ potential can be applied to the grid (G).

Theory : If for a fixed anode voltage V_1, a curve R_1 is drawn with the grid voltage (V_g) as abscissa and the corresponding anode current (i_a) as ordinate then this curve is called the *static characteristic* curve of the triode for the fixed anode potential V_1. For different values V_2, V_3 etc. of the anode potential we get different characteristic curves R_2, R_3 etc. as are shown in Fig. 87.

The Fig. 87, shows that a given change (RQ) of anode current can be caused either (i) by changing the grid voltage (V_g) by PQ [when the anode voltage (V_a) is kept fixed at (V_3)] or (ii) by changing the anode potential (V_a) by ($V_3 - V_2$)

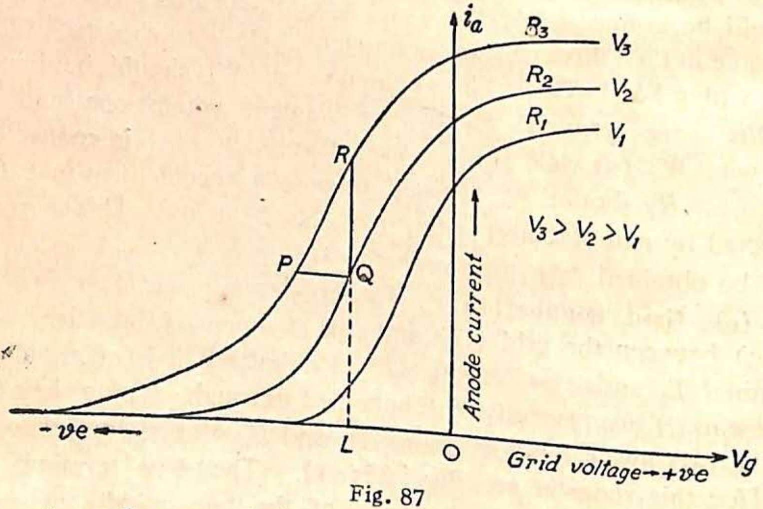

Fig. 87

[when the grid voltage (V_g) is kept fixed at OL]. The three constants of the valve, viz—(*i*) amplifying factor (μ), (*ii*) internal resistance (R_i) and (*iii*) mutual conductance (g_m) can be obtained from the straight portion of the static characteristic curves as follows :

(*i*) *The amplifying factor* (μ) of the valve is given by,

$$\mu=\frac{\text{change in } V_a \text{ for a definite change of } i_a \text{ (when } V_g \text{ is const.)}}{\text{change in } V_g \text{ for the same change of } i_a \text{ (when } V_a \text{ is const)}}.$$

$$\text{or, } \mu=\frac{\delta V_a}{\delta V_g}=\frac{V_3-V_2}{QP} \text{ (from curves } R_3 \text{ and } R_2\text{)} \quad \cdots \quad (1)$$

(*ii*) *The internal resistance* (R_i) of the valve is defined as the ratio of the change in the anode voltage (δV_a) to the corresponding change in the anode current (δi_a) when the grid voltage is kept constant. Hence we get,

$$R_i=\frac{\delta V_a}{\delta i_a}=\frac{V_3-V_2}{RQ}\times 1000. \text{ [when } V_g \text{ is fixed]} \quad (2)$$

[where i_a (RQ) is in milliamperes]

(*iii*) *Mutual conductance* (g_m) of the valve is defined as the ratio of the change in anode current (δi_a) to the corresponding change in gird voltage (δV_g) when the anode voltage is kept constant. Thus we get,

$$g_m=\frac{\delta i_a}{\delta V_g}=\frac{RQ}{PQ\times 1000} \text{ [when } V_a \text{ is fixed]} \quad \cdots \quad \cdots \quad (3)$$

[where $i_a(=RQ)$ is in miliamperes].

$$\text{Again, } \mu=\frac{\delta V_a}{\delta V_g}=\frac{\delta V_a}{\delta i_a}\times\frac{\delta i_a}{\delta V_g}=R_i\times g_m \quad \cdots \quad \cdots \quad (4)$$

The points *P, Q* and *R* on the curves should only be taken on their straight portions, for μ, R_i and g_m remain constant in that portion only.

Procedure :

(*a*) *To draw* (V_g-i_a) *curves*--(*i*) A high tension of 90 volts (say) is applied to the anode by joining the clip C' to the $-ve$ pole of a certain cell of the battery B'_1 or to a certain point of the variable resistance R_3 (when D.C. main is employed).

(*ii*) The key K_2 is closed and the variable resistance R_2 is adjusted to have a current in the filament (as indicated by the ammeter *M*) as prescribed by the manufacturer.

(*iii*) Maximum $-ve$ potential is applied to the grid by moving the sliding contact of rheostat R_1 towards B_2 and turning the rocker of commutator towards C_1 C_2. This grid voltage is recorded by the voltmeter V_g. To note the corresponding anode current, the key K_1 (or the switch S when D.C. main is employed) is closed and milliammeter (*M.A.*) reading is taken.

(iv) The sliding contact C is now gradually moved towards B_1 until the grid potential is reduced to zero. At each stage, the grid voltage V_g is noted by the voltmeter (V_g) while the corresponding anode current (i_a) is noted by the millimmeter (*M.A.*). The key K_1 (or the switch S in the anode circuit) is to be kept open during the time of new adjustment of the gird potential.

(*v*) To apply $+ve$ potential to the grid, the rocker of the commutator is turned towards C_2 C_4 and the sliding contact of the rheostat R_1 is moved from B_1 towards B_2 until the maximum $+ve$ grid voltage is applied to the grid. At each stage, the grid voltage and anode current are noted as before.

(*vii*) The experiment is repeated for two other anode voltages (say 100 volts and 110 volts).

(*viii*) For each anode voltage, a curve is drawn with the grid voltage (V_g) as abscissa and the corresponding anode current i_a (in milli-amperes) as the ordinate, which is the static characteristic curve of the triode for the given anode voltage. We get three such curves R_1, R_2 and R_3 for three different anode potentials V_1, V_2 and V_3 [Fig. 87]. Selecting the straight portions of a pair of curves μ. R and g_m are separately determined by employing the curves R_3 and R_2, R_3 and R_1 and also R_2 and R_1. From these, mean values of μ, R, and g_m are found out.

(*b*) *To draw* ($V_a - i_a$) *curves.*—For a fixed grid voltage V_g [which can be obtained from the voltmeter V_g connected across B_1 and B of Fig. 86], various values of anode current (i_a) [measured by the milliammeter *M.A.*] corresponding to various values of anode voltages (V_a) [measured by the voltmeter V_a

are found out. By plotting anode voltage V_a along x-axis and its corresponding anode current i_a in milliamperes along y-axis, we shall get a curve which is also known as the *static characteristic curve* of the triode. In this way we may draw several $(i_a - V_a)$ curves R_3, R_2, R_1, etc. [as are shown in Fig. 88] corresponding to fixed grid voltages, Vg_3, Vg_2, Vg_1, etc. $[Vg_3 > Vg_2 > Vg_1]$.

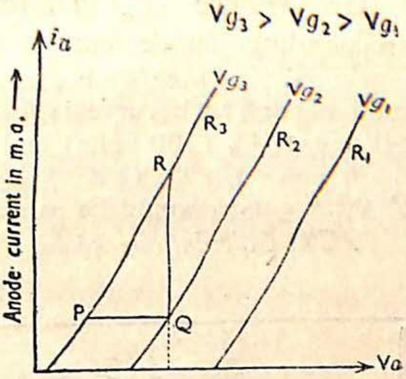

Fig. 88

Experimental data :

(A) *Record of data for drawing* $(V_g - i_a)$ *curves* :—

TABLE I

Filament voltage= . . . volts.

" current= . . . amps.

1	Applied grid voltage (V_g) in volts⟶							
2	Corresponding anode current (i_a) in milli-amperes when $V_a = V_1 = ..$ volts⟶							
3	Corresponding anode current (i_a) in milli-amperes when $V_a = V_2 =$ volts⟶							
4	Corresponding anode current (i_a) in milli-amperes when $V_a = V_3 = ...$volts⟶							

N.B. [Three $(V_g - i_a)$ curves are to be drawn with data of columns (1 & 2) ; (1 & 3) and (1 & 4)].

(B) *Drawing of ($V_g - i_a$) curves :—*

Grid voltage (V_g) in volts is plotted along *x*-axis while the corresponding anode current (i_a) in milliamperes is plotted along *y*-axis. Three such curves are to be drawn on the same graph paper [each curve is for a fixed anode voltage, say V_1 (90 volts), V_2 (100 volts) and V_3 (110 volts) by using the data of columns (1 & 2), (1 & 3) and (1 & 4) of table I]. The nature of these curves would be as shown in Fig. 87.

(C) *Calculations of μ, R_i and g_m from ($V_g - i_a$) curves :—*

TABLE II

Curves employed	Change in V_g in volts = $\delta V_g = PQ$	Change in i_a in amps. = $\delta i_a = QR/1000$	Change in V_a in volts = δV_a	$\mu = \delta V_a / PQ$	R_i in ohms $= 1000 \frac{\delta V_a}{QR}$	g_m in ohm^{-1} $= \frac{QR}{1000 PQ}$	Mean μ	Mean R_i in ohms	Mean g_m in ohm^{-1}
R_3 and R_2	...	...	... $(V_3 - V_2)$	....	....	...	...	...	...
R_3 and R_1	...	...	... $(V_3 - V_1)$	...	....	...			
R_2 and R_1	...	...	... $(V_2 - V_1)$	...	...	...			

(D) *Record of data for drawing ($V_a - i_a$) curves :—*

TABLE III

[Make a table, like the table I with the following changes —(*i*) In column 1, write 'anode voltage' (V_a), in place of 'grid voltage' (V_g) (*ii*) In columns 2, 3 and 4, write V_g for V_a and V_{g1}, V_{g2}, V_{g3} for V_1, V_2 and V_3 respectively].

(E) *Drawing of ($V_a - i_a$) curves :—*

Anode voltage (V_a) in volts is plotted along *x*-axis while the corresponding anode current (i_a) in milliamperes is plotted along *y*-axis. Different curves are drawn on the same graph paper, each being for a fixed grid voltage. The nature of these curves is shown in Fig. 88.

(F) *Calculation of μ, R_i, and g_m from ($V_a - i_a$) curves* :—

TABLE IV

Curves employed	Change in V_g in volts $=\delta V_g$	Change in i_a in amps. $=\delta i_a$ $=QR/1000$.	Change in V_a in volts $=\delta V_a=PQ$	$\mu=PQ/\delta V_g$	R_i in ohms $=1000\frac{PQ}{QR}$	g_m in ohm^{-1} $=\frac{QR}{1000\,\delta V_g}$	Mean μ	Mean R_i in ohms	Mean g_m in ohm^{-1}
R_3 and R_2	... $(V_{g3}-V_{g2})$	...	...	...	....	...			
R_3 and R_1	$(V_{g3}-V_{g1})$	...	...	...	....	...	...	...	...
R_2 and R_1	... $(V_{g2}-V_{g1})$	...	...	...	...	....			

N.B. [If only ($V_g - i_a$) curves are wanted then omit the items (*D*), (*E*) and (*F*) of 'experimental data' and also omit item (*b*) of 'procedure'].

Discussions : (*i*) As μ, R_i and g_m are constants at the straight portion of the curves, the points *P*, *Q* and *R* should be taken at the straight portions only of the curves.

(*ii*) The filament heating current should be kept constant throughout the experiment by adjusting R_2, if necessary.

(*iii*) The +*ve* of milliammeter (*M.A.*) should be joined to the +*ve* of high tension battery B'_1.

Oral Questions and their Answers

1. What is a triode valve and how does it differ from a diode? Why they are called valves?

A triode has three electrodes, *viz.*, anode, filament or cathode and grid while a diode has only two electrodes, *viz.*, anode and filament. As the current in the triode or diode always flows in one direction (from anode to cathode) it is called valve in analogy with a pressure-valve which allows a fluid to flow in one direction only.

2. What are the functions of filament, anode and grid ?

Filament emits thermo-electrons when it is heated by an electric current ; anode (which is kept at a high +*ve* potential) draws these electrons and produces anode current from anode to cathode while the grid serves as the control electrode which can accelerate or retard the thermo-electrons according as its voltage is made +*ve* or −*ve*.

3. What is space charge? [See item (*i*) of the construction of triode].

4. Why the grid is made of wire-gauge cylinder ?

Most of the electrons from filament will pass through the clear space of the wire-gauge and will attach themselves on the anode causing an anode current.

5. What are the uses of triode ?

It is used (*i*) for amplifying feeble oscillatory voltage, (*ii*) in rectifying alternating or oscillatory current, and (*iii*) to produce undamped high frequency current.

6. What is the characteristic curve of a triode ?

The curve connecting grid-voltage and anode-current (for a fixed anode-voltage) is called characteristic curve of a triode ?

7. What positions of the characteristic curve are used to produce (*i*) amplification and (*ii*) rectification ?

(*i*) The straight portion of the characteristic curve is employed to produce amplification. If the initial grid-voltage (v_g) corresponds to the middle point of the straight portion of the characteristic then a small equal change of grid voltage on either side of v_g will cause a large equal increment and decrement of anode current (i_a). For rectification of an oscillatory voltage, the initial grid-voltage (v_g) is to be kept at the bend-point of the characteristic so that a small equal change of grid-voltage on either side of v_g, will cause an unequal increment and decrement of anode current causing a net direct current in the circuit. This is known as the anode-bend rectification. Similarly grid-bend (bend-point of grid-voltage grid-current curve) rectification can be made.

8. Is there any other valve in which more than three electrodes are employed ?

There are tetrodes, pentodes, etc. having four, five, etc. electrodes giving greater efficiency and selectivity.

Appendix A

TABLE OF PHYSICAL CONSTANTS

(Light and Electricity)

1. Refractive indices of substances for D-line (5893Å).

Substance	Refractive index	Substance	Refractive index	Substance	Refractive index
Alum	1·456	Aniline	1·59	Olive oil	1·46
Glass (crown)	1·48-1·61	Benzene	1·504	Paraffin oil	1·44
Glass (flint)	1·53-1·96	Carbon disulphide	1·632	Sulphuric acid	1·43
Mica	1·56-1·60	Carbon tetrachloride	1·464	Turpentine	1·47
Rock salt	1·544	Chloroform	1·449	Water	1·333
Alcohol (ethyl)	1·362	Ether	1·354		
Alcohol (Methyl)	1·329	Glycerine	1·47		

2. Wavelengths of some of the important emission lines in Angstrom units (1 A. U.$=10^{-8}$ cm.).

[The colours are indicated by the letters v, i, b, g, y, o, r]

Substance	λ in Å	Substance	λ in Å	Substance	λ in Å
Argon	4159 v	Helium	3889 v	Neon	5765 y
	4192 v		4026 v		5853 y
	4198 v		4471 b		5945 o
	4201 v		4713 b		6075 o
	4259 b		4922 bg		6383 o
	4703 b		5016 g		6402 o
	6031 o		5876 y		6507 r
Copper arc in vacuo	5106 g		6678 r		
	5153 g		7065 r	Potassium chloride in flame	4044 v
	5218 g	Hydrogen	3970 v		4047 v
	5700 y		4102 v		7668 r
	5782·09 y		4340 b		7702 r
	5782·16 y		4861 gb	Sodium chloride in flame	5890 y (D$_2$)
			6563 r		5896 y (D$_1$)
		Mercury lamp	5460 g		
			5770 y		
			5791 y		
			6152 o		
			6253 o		

3. Specific resistance and temperature-coefficient of resistance.

Substance	Specific resistance in (ohm-cm.)	Temp. Coeff of resistance in $°C^{-1}$	Substance	Specific resistance in (ohm-cm.)	Temp. Coeff. of resistance in $°C^{-1}$
Aluminium	32·1 $\times 10^{-6}$	38 $\times 10^{-4}$	Manganin	44·5 $\times 10^{-6}$	·02 to ·5 $\times 10^{-4}$
Brass	6 – 9 ,,	10 ,,	Nickel	11·8 ,,	27 ,,
Constantan	49 ,,	– ·4 to ·1 ,,	Nichrome	110 ,,	1·7 ,,
Copper	1·78 ,,	42·8 ,,	Platinum	11 ,,	37 ,,
German Silver	16 to 40 ,,	2·3 to 6 ,,	Silver	1·63 ,,	40 ,,
Iron (wrought)	13·9 ,,	62 ,,	Steel	19.9 ,,	16 to 42

4. E.M.F. of cells in volts.

Cell	E.M.F. in volts	Cell	E.M.F. in volts
Bunsen	1·85	Weston Cadmium at $t°C$	1·083 – ·0000406 $(t-20)$
Daniell	1·08	Acid storage cell	2
Leclanche's	1·4	Alkali ,, ,,	1·25

5. Electro-chemical equivalents (E.C.E.).

Substance	E.C.E. in gms./coluomb
Copper	·0003293
Hydrogen	·00001044
Silver	·0011182

APPENDIX B

MATHEMATICAL TABLES

Uses of Logarithm and Antilogarithm Tables

These tables are very useful for making an easy simplification of a fraction containing arithmetical figures. For this purpose, find separately the sum of the logarithms of numbers in the numerator and denominator. Then subtract the logarithm of the denominator from that of the numerator and find the antilogarithm (from the antilogarithm table) of this difference so obtained. This antilogarithm is the required result of the simplification of the fraction. Procedure will be best understood from an example given below. (For details, see *Logarithm and other Tables* by Frank Castle).

Example :

Simplify :— $y = \dfrac{760 \times (25{\cdot}76)^3 \times ({\cdot}3)^{\cdot 4}}{(51{\cdot}6 + 280{\cdot}19) \times (57{\cdot}832)^{\frac{1}{7}}}$

Logarithms of numerator are,

$\log 760 \quad \ldots \quad \ldots \quad \ldots \quad = 2{\cdot}8808.$

$\log (25{\cdot}76)^3 = 3 \log (25{\cdot}76) = 3\ (1{\cdot}4109) \quad = 4{\cdot}2327.$

$\log ({\cdot}3)^{\cdot 4} \quad = {\cdot}4 \log ({\cdot}3) = \frac{4}{10}\ (\bar{1}{\cdot}4771) \quad = \frac{4}{10}\ (\overline{10} + 9{\cdot}4771)$

$= 4(\bar{1}{\cdot}9477) = \bar{1}{\cdot}7908.$

Logarithms of denominator are,

$\log (51{\cdot}6 + 280{\cdot}19) = \log (331{\cdot}79) = \log (331{\cdot}8) = 2{\cdot}5208.$

$\log (57{\cdot}832)^{\frac{1}{7}} = \frac{1}{7} \log (57{\cdot}832) = \frac{1}{7} \log (57{\cdot}83) = \frac{1}{7}\ (1{\cdot}7621)$

$= {\cdot}2517.$

Sum of the logarithms of numerator $= 2{\cdot}8808 + 4{\cdot}2327 + \bar{1}{\cdot}7908 = 6{\cdot}9043$

Sum of the logarithms of denominator $= 2{\cdot}5208 + {\cdot}2517 = 2{\cdot}7725$

$\log y = \{$log. of Numr.—log. of Denomr.$\}$.

$= (6{\cdot}9043 - 2{\cdot}7725) = 4{\cdot}1318.$

Antilog. of ·1328 (from table) = 1355.

$\therefore \quad y = 13550.$

LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						5	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	36
11	0414	0453	0492	0531	0569						4	8	12	16	20	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	18	22	26	29	33
12	0792	0828	0864	0899	0934						3	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	6	10	13	16	19	23	26	29
						1303	1335	1367	1399	1430	3	7	10	13	16	19	22	25	29
14	1461	1492	1523	1553	1584						3	6	9	12	15	19	22	25	28
						1614	1644	1673	1703	1732	3	6	9	12	14	17	20	23	26
15	1761	1790	1818	1847	1875						3	6	9	11	14	17	20	23	26
						1903	1931	1959	1987	2014	3	6	8	11	14	17	19	22	25
16	2041	2068	2095	2122	2148						3	6	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	16	18	21	23
17	2304	2330	2355	2380	2405						3	5	8	10	13	15	18	20	23
						2430	2455	2480	2504	2529	3	5	8	10	12	15	17	20	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	17	19	21
						2672	2695	2718	2742	2765	2	4	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8

LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1223	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2055	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

NATURAL SINES.

Degrees.	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0° 3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences.				
											1	2	3	4	5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	15
5	·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	12	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2232	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5888	5402	5417	5432	2	5	7	10	12
33	·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	10	12
36	·587	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10

NATURAL SINES.

Degrees.	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences.				
											1	2	3	4	5
45	·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2	4	6	8	10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	·7547	7558	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	2
85	·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000	0	0	0	0	0
90	1·000														

NATURAL TANGENTS

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences				
											1	2	3	4	5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3	6	9	12	16
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	7	10	13	16
20	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	11	14	18
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	8	11	15	19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	12	15	19
30	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	9	14	19	24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	16	21	26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29

NATURAL TANGENTS

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences				
											1	2	3	4	5
45	1·0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	6	12	18	24	30
46	1·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6	12	18	25	31
47	1·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	13	19	25	32
48	1·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7	13	20	27	33
49	1·1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	14	21	28	34
50	1·1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	22	29	36
51	1·2349	2393	2437	2482	2527	2572	2617	2662	2708	2753	8	15	23	30	38
52	1·2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	16	24	31	39
53	1·3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8	16	25	33	41
54	1·3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9	17	26	34	43
55	1·4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	18	27	36	45
56	1·4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	10	19	29	38	48
57	1·5399	5458	5517	5577	5637	5697	5757	5818	5880	5941	10	20	30	40	50
58	1·6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	11	21	32	43	53
59	1·6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	23	34	45	56
60	1·7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	12	24	36	48	60
61	1·8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	13	26	38	51	64
62	1·8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14	27	41	55	68
63	1·9626	9711	9797	9883	9970	2·0057	2·0145	2·0233	2·0323	2·0413	15	29	44	58	73
64	2·0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16	31	47	63	78
65	2·1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17	34	51	68	85
66	2·2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55	73	92
67	2·3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60	79	99
68	2·4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65	87	108
69	2·6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	47	71	95	119
70	2·7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26	52	78	104	131
71	2·9042	9208	9375	9544	9714	9887	3·0061	3·0237	3·0415	3·0595	29	58	87	116	145
72	3·0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32	64	96	129	161
73	3·2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36	72	108	144	180
74	3·4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	81	122	163	204
75	3·7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46	93	139	186	232
76	4·0108	0408	0713	1022	1335	1653	1976	2303	2635	2972	53	107	160	213	267
77	4·3315	3662	4015	4374	4737	5107	5483	5864	6252	6646					
78	4·7046	7453	7867	8288	8716	9152	9594	5·0045	5·0504	5·0970	Mean differences cease to be sufficiently accurate.				
79	5·1446	1929	2422	2924	3435	3955	4486	5026	5578	6140					
80	5·6713	7297	7894	8502	9124	9758	6·0405	6·1066	6·1742	6·2432					
81	6·3138	3859	4596	5350	6122	6912	7720	8548	9395	7·0264					
82	7·1154	2066	3002	3962	4947	5958	6996	8062	9158	8·0285					
83	8·1443	2636	3863	5126	6427	7769	9152	9·0579	9·2052	9·3572					
84	9·5144	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20					
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95					
86	14·30	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46					
87	19·08	19·74	20·45	21·20	22·02	22·90	23·86	24·90	26·03	27·27					
88	28·64	30·14	31·82	33·69	35·80	38·19	40·92	44·07	47·74	52·08					
89	57·29	63·66	71·62	81·85	95·49	114·6	143·2	191·0	286·5	573·0					
90	∞														

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